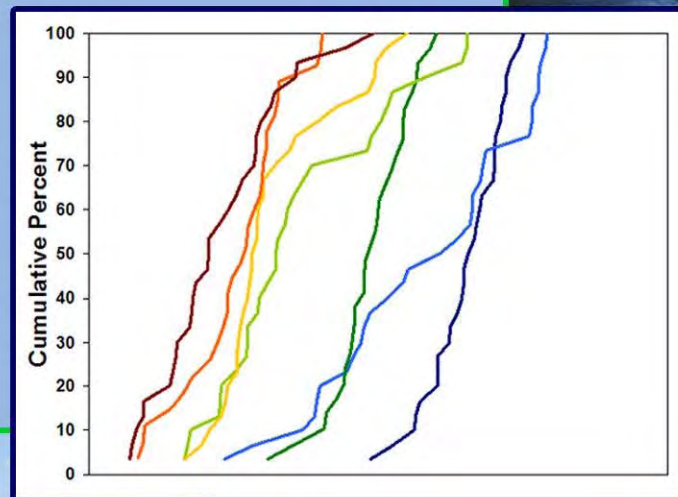


Development of a Probability-Based Monitoring and Assessment Strategy for Select Large Rivers within US EPA Region 5

Final Report

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1.0. INTRODUCTION

1.1 Purpose

This effort is part of the U.S. Environmental Protection Agency's (USEPA) Environmental Monitoring and Assessment Program (EMAP) and represents a synthetic geographical and resource based approach. This strategy informs those interested in the tools and approaches for deriving assessments of condition of large and great river resources. It guides them through the various phases of project implementation as detailed in the related Research Plans and Quality Assurance Project Plans (QAPP).

The Environmental Monitoring and Assessment Program (EMAP) was established to develop and demonstrate the monitoring tools necessary to answer broad questions about the quality of our Nation's ecological resources. EMAP has produced techniques needed by States and Tribes to fulfill some of the requirements of the Clean Water Act (CWA). The CWA specifies that States and Tribes must address the three following general questions: 1) what is the condition of the Nation's waters?, 2) are conditions changing over time?, and 3) what factors determine conditions or cause conditions to change? While these questions appear simple, they are profoundly complicated by the need to define "condition" and "surface waters".

Such information is the most direct way EMAP supports state and tribal managerial decision-making processes. The developed approaches are consistent with the monitoring needs of the States and Tribes as they endeavor to answer the questions raised by the Clean Water Act (CWA) (Section 305(b)).

This project involves a survey of selected tributaries to the Upper Mississippi and Ohio Rivers within Region V. The tributary effort will involve data collection, analysis and reporting. The data collected as part of the tributary effort will be available to USEPA to use in support of the Environmental Monitoring and Assessment Program Great River Ecosystem (EMAP GRE) effort.

This project will serve to develop, demonstrate, and promote the EMAP approach to monitoring and assessment in the selected large river tributaries to the great rivers. The results of this study will improve surface water monitoring and assessment programs and will advance and institutionalize the use of probability-based monitoring across multiple states and USEPA regions.

The purpose of this project is to enable researchers to estimate, with known statistical confidence, the current status, geographic extent and distribution of large river resources within USEPA, Region 5. It will also allow researchers to examine the intra- and inter-river variability of landuse patterns that may influence the condition of the same large river resources. Later uses of the database may include developing and refining reference conditions for non-wadeable, large river resources on a regional basis. This is an important precursor to biocriteria development. A further use of the data will be to compare assessment endpoints reached utilizing data collected following a probability design to assessment endpoints reached by individual state agencies making assessment with more labor-intensive (and often biased) targeted approaches. A secondary goal is the development of an IBI or similar assessment tool that is applicable across a large geographic area such as USEPA Region 5. Mebane et al (2003) developed such a tool for the Pacific Northwest.

Promulgating the use of the EMAP approach for river monitoring has been a fundamental goal of EMAP and is a high priority of this project. Data from this project will be useful for States, management agencies, and the public to understand the current or baseline conditions of river resources. These data will make more comprehensive reports of the conditions in streams and rivers in the nation as mandated in the Clean Water Act. The indicators, designs, and analytical methods are the truly valuable legacy products of the project. These are the tools with which States will be able to coherently monitor and assess river ecosystems in the future. They provide the means to discover trends in river condition and to evaluate the impact of management policies and restoration attempts.

1.2. Rationale

Large rivers are an important ecological resource and constitute a significant water quality management challenge in USEPA Region 5. In addition to their economic and natural resource value, they are the focus of numerous environmental and natural resource management issues. In particular, many of the major and significant NPDES permitted discharges occur to these water bodies. Despite their importance and visibility, biological assessment methodologies are not as formally developed nor as widely employed as in smaller, wadeable streams, and are only recently receiving emphasis by all of the states. Sufficiently robust, refined, and documented large river fish assemblage assessment approaches and coverages have been developed by only two Region 5 states and ORSANCO on a statewide or region wide basis (Yoder and Smith 1999; Lyons et al. 2001; Emery et al. 2003). These were developed entirely within the jurisdiction of each entity and are based on methods and equipment that may or may not be translatable across the region. Ohio EPA adopted standardized methods and has adopted numeric biocriteria based on calibrated multimetric indices. Routine assessments of large river fish assemblages have been conducted for more than 25 years (Ohio EPA 1987; Yoder and Smith 1999). ORSANCO recently developed a fish assemblage method and index for the Ohio River (ORFI; Emery et al. 2003) and continues to apply it within their monitoring program. Wisconsin also developed a fish assemblage method and index (Lyons et al. 2001); all three efforts employ different equipment and methods, but are conceptually similar. Indiana has developed a working IBI for the Wabash River (Simon and Stahl 1998). The remaining Region 5 states (Illinois, Michigan, and Minnesota) also sample large rivers, but have not done so as extensively, nor have they developed numeric biocriteria.

Large rivers present challenges including shared and multiple jurisdictions. Therefore, a regionally consistent assessment of the ichthyofauna would constitute a major advancement in the management of aquatic resources. Conducting biological assessments in large rivers is widely regarded as being more difficult and resource intensive than for smaller, wadeable streams, hence the emphasis on this latter waterbody type by most states and USEPA guidance. The intent of this project was to initiate a process by which condition of the large river resources of a whole region was made available to the states and USEPA. This was and is an important and requisite first step to attaining the goal of having fully developed and calibrated biological assessment tools and biological criteria, which in turn supports specific water quality management programs within the states and Region 5. Of particular interest here was the assessment of the effectiveness of NPDES permits on an individual and collective basis by using the health of the biota as a keystone measure of response.

The principal task of this project was to collect and analyze biological sampling data for the purpose of demonstrating the indicators and monitoring designs that yield unbiased estimates of condition for entire resource populations. Collaborating organizations included the states of Illinois, Indiana, Minnesota, Wisconsin, and Ohio, all of which contain large rivers that are

tributaries to the Ohio and/or upper Mississippi Rivers. Collaboration with USEPA-ORD also took place as appropriate. Collaboration with the states and USEPA occurred with monitoring and studies already planned by each or as a part of this project. The Midwest Biodiversity Institute provided assistance with data collection and logistics as appropriate.

1.3. Geographic Area of Coverage

The geographic area of coverage of this study primarily included the large, non-wadeable rivers that are tributary to the Upper Mississippi River (above the confluence with the Ohio River) and the Ohio River that occur within Region 5 states (Figure 1). For the purposes of this project, large rivers are defined as the primary tributaries of the Ohio and upper Mississippi rivers and subsequent tributaries that drain land areas >1000 square miles. Non-wadeable rivers that require boat electrofishing to secure an adequate assemblage assessment include drainage areas <1000 square miles, but they were not included here. Of primary interest of this study was to address the transition between great and large rivers. The Ohio and Mississippi are considered to be great rivers for the purposes of EMAP GRE and are not included here; however, the ecological definition of great rivers also includes portions of the larger Ohio and upper Mississippi tributaries such as the lower Wabash and Illinois Rivers (Simon and Emery 1995). The reality of the ecological definition has functional implications for both sampling methods and the development of biological assessment tools such as multimetric indices (e.g., IBI), and eventually biocriteria.

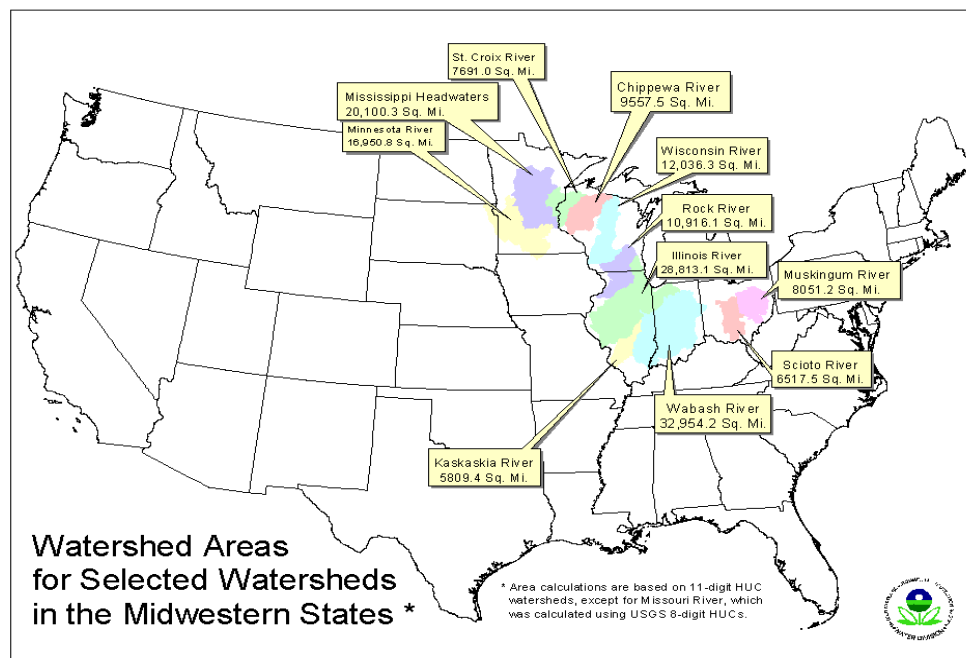


Figure 1. Large river basins and candidate rivers for testing and comparing biological assessment methods in Region V.

1.4. Objectives, Approach, and Methodology

Two Region 5 states and ORSANCO have developed and used standardized methods for sampling and assessing large and great river fish and macroinvertebrate assemblages on a

statewide or region wide basis. Ohio EPA has methods for both assemblages and has adopted numeric biocriteria based on multimetric indices; routine assessments have been conducted for more than 25 years (Ohio EPA 1987; Yoder and Smith 1999). ORSANCO recently developed a fish assemblage method and index (ORFin; Emery et al. 2003); a macroinvertebrate method is in development. Wisconsin developed a fish assemblage method and index (Lyons et al. 2001) and is interested in developing a macroinvertebrate assemblage method. Indiana has developed a working IBI for the Wabash River. The other states (Illinois, Minnesota) perform some biological monitoring in their non-wadeable rivers, but in a less systematic manner and without the benefit of regionally calibrated assessment tools.

This project focused on 4 main objectives:

Objective 1: *Provide an unbiased estimate of ecological condition for a portion of the large river resources within USEPA Region 5.*

We worked with EMAP planners to develop an EMAP sampling design of 30 sites selected for each of the 11 large river tributaries to the Ohio and Upper Mississippi Rivers. We sampled as many of the rivers as possible, but were limited by unfavorable weather and flow conditions. Landscape GIS data and availability of other data were used to prioritize rivers. The design for each river covered the linear extent of the river from its confluence with either the Ohio or Mississippi Rivers upstream to a point designating a drainage area greater than or equal to 1000 sq. miles. A meaningful point location on each tributary such as a confluence or dam nearest the 1000 sq. mile cutoff was selected as the upper bound. At as many of the 30 sampling locations as possible, fish assemblage data was collected at a single sampling site, following standardized methods.

We used common indices such as the Modified Index of Well-Being (MIwb) and the Index of Centers of Density (ICD) to describe changes in fish community condition. A statistical estimate of condition came through the development and application of a multimetric index, which we call the Fish Assemblage Quality Index (FAQI).

Objective 2: *Provide an estimate of the geographic extent and distribution of key large river resource elements (T/E species, species of special concern, alien/invasive species) and broad changes in fish assemblage attributes within USEPA Region 5.*

We described and discussed the distribution of key species and provided distribution maps

Objective 3: *Examine intra- and inter-river variability of landuse patterns that may influence the condition of large river resources.*

We described the relationship between catchment attributes (riparian and in-river habitats and water chemistry) and landuse practices and how these in turn affect the biology of the systems.

Objective 4: *Compare assessment endpoints reached following the probability design to endpoints reached for each river by individual states using more labor intensive, targeted approaches, discussing the strengths/weaknesses and tendencies of broader, regional designs.*

We were unable to focus on assessment endpoints (pass/fail; impaired/non-impaired) as we did not attempt to describe impaired waters. Instead, we focused on comparing the results of our regionally developed FAQI to state or water body specific IBIs in place and in use by the state

agencies. We compared our index to existing indices and discussed the general tendencies of the regional tool developed for a much broader geographic scale.

2.0. MATERIALS AND METHODS

2.1. STUDY AREA/ SITE DESCRIPTIONS

2.1.1. St. Croix River

The St. Croix River is a sixth order tributary to the upper Mississippi River that originates at St. Croix Lake near Solon Springs, Wisconsin. The St. Croix River lies within the Superior Upland and Central Lowland physiographic provinces (DeLong 2005). It is approximately 170 mi (276 km) long with a mean discharge of 131 m³/s. Approximately 80% (129 miles) of the St. Croix River forms part of the boundary between Wisconsin and Minnesota. The upper 20% of the river is entirely within Wisconsin. The watershed covers approximately 20,030 km² (7,760 mi²) and extends from near Mille Lacs Lake in Minnesota on the west to near Cable, Wisconsin, on the east. Approximately 46% of the watershed is located in Minnesota. Originating in Upper St. Croix Lake near Solon Springs, Wisconsin, at an elevation of 337 m (1,105 ft); it flows southwest to its confluence with the Mississippi River at Prescott, Wisconsin (elevation 206 m, 675 ft) (Young and Hindall 1973). The Namekagon River is a 5th order stream that drains northwestern Wisconsin and joins the St. Croix above Danbury, Wisconsin. The St. Croix River is a National Wild and Scenic Riverway and is considered one of the best recreational rivers in the Midwest. The river exhibits moderate sinuosity and winds through primarily forested regions of Wisconsin and Minnesota in a series of rapids and pools. The riverbed is primarily tillage with coarse substrates throughout (DeLong 2005).

The watershed is largely forested, comprised of both mixed deciduous and evergreen forest. Forest, pasture/ hay, rowcrops and woody wetlands respectively combine to comprise the majority of the total basin land cover. Riparian land cover is 49.6% forested and 24.4% agricultural. Human induced land use (primarily agricultural) comprises 34.3% of the total watershed area. The watershed is minimally impacted by industry, transportation, and mining operations, each accounting for less than 1% of the total watershed area. The watershed is largely rural as residential areas represent less than 1% of its spatial composition combined. Likewise, the St. Croix River is minimally impacted throughout its length. The St. Croix River land cover map is located in Appendix 1.

A total of thirty sites were sampled on the St. Croix between river miles 4 and 129 during the 2004 sampling season (index period) (Figure 2). Of the thirty target sites, 19 were sampled during the day and the remaining 11 were sampled at night (Appendix 1).

2.1.2. Wabash River

The Lower Wabash River is a seventh order tributary to the Ohio River and incorporates the drainage basin between Honey Creek in Vigo County and the mouth of the Wabash River at the Ohio River in Posey County. The Wabash River lies within the Central Lowland and Interior Low Plateau physiographic provinces (White et al. 2005). The river is approximately 475 mi (765 km) long with a mean discharge of 1,001 m³/s. The basin has an area of 28,233 km² (1,339 mi²) and includes most of Sullivan and Posey Counties, plus parts of Vigo, Greene, Knox, Gibson, and Vanderburgh Counties in southwestern Indiana (Hoggatt 1975). The major cities and towns in the basin are Vincennes, Terre Haute, Indianapolis, Muncie, Lafayette, and Logansport. The Lower

Wabash River valley is a broad, flat glacial drainage channel that includes winding channels, a wide flood plain, and adjacent terrace levels. The valley floor ranges from 3 to 10 mi in width. Local relief on the valley floor is typically less than 50 ft except for isolated hills (Fidlar 1948). Undulating, rolling plains with a thin cover of till, loess, and silt characterize the area east of the Wabash terraces. Local relief is greater in the uplands of southern Posey County beyond the maximum extent of glaciation. Broad, flat lake plains that form present day bottomlands east of the terraces were created during Wisconsinian time when tributary valleys became ponded by the rapid aggregation of the valley floor (Fidlar, 1948). In the surrounding uplands, bedrock terraces were eroded on resistant limestone and shale.

Watershed land cover is largely agricultural. Rowcrops, forest and pasture/hay combine to comprise the majority of the total basin land cover. Riparian land cover is 67% agricultural and 19.3% forested. Human induced land use comprises 81.1% of the total watershed area and is primarily agricultural. The watershed is heavily impacted by rowcrops and pasture/hay, and is minimally impacted by mining, industry and transportation. The basin is largely rural, as residential areas represent roughly 5% of its spatial composition. The Wabash River is likewise heavily impacted throughout its length. The Wabash River land cover map is located in Appendix 1.

A total of thirty sites were sampled on the Wabash River between river miles 8 and 380 during the 2004 sampling season (Figure 3). Of the thirty target sites, nine were sampled during the day and the remaining twenty-one sites were sampled at night (Appendix 1).

2.1.3. Wisconsin River

The Wisconsin River is an eighth order tributary of the Mississippi River, approximately 430 mi (692 km) long, in the state of Wisconsin and drains an area of 30,889 km². The Wisconsin River lies within the Central Lowland and Superior Upland physiographic provinces (DeLong 2005). It originates in the forests of the Lake District of northern Wisconsin, in Lac Vieux Desert near the border of the upper peninsula of Michigan. It flows southward across the glacial plain of central Wisconsin, passing Wausau and Stevens Point. In southern Wisconsin it encounters the terminal moraine formed during the last ice age, where it forms the Dells of the Wisconsin River. North of Madison, it turns to the west, flowing across the hills of southwest Wisconsin and joins the Mississippi approximately 10 mi (16 km) south of Prairie du Chien. It is navigable up to the town of Portage, 200 mi (320 km) from its mouth, where it is separated from the Fox River by only 2 mi (3.2 km). The Wisconsin is impounded in 26 places for hydroelectric power and natural flows are hence substantially modified. The middle reaches of the Wisconsin River were formerly impacted by industrial and municipal point sources. Water quality has since improved. The lower Wisconsin River is a shallow, sandy river of braided channels among numerous vegetated islands. Turbulent currents create and obliterate sandbars and bank holes with unpredictable frequency. Near Muscoda (RK 71.5), the average discharge is 247 m³/s (Holmstrom et al. 1996). As the Wisconsin River passes under a railroad bridge at RK 2.6, it becomes nearly indistinguishable from the side channels and backwaters in Navigation Pool 10 of the upper Mississippi River.

The watershed is largely forested, comprised of both mixed deciduous and evergreen forest. Forest, pasture/ hay, rowcrops and woody wetlands respectively combine to comprise the majority of the total basin land cover. Riparian land cover is 43% forested and 32.1% agricultural. Human induced land use comprises 41% of the total watershed area and is primarily agricultural. The watershed is minimally impacted by industry, transportation, and mining operations, each accounting for less than 1% of the total watershed area. The watershed is largely rural, as

residential areas represent less than 1% of its spatial composition combined. The Wisconsin River land cover map is located in Appendix 1.

A total of twenty-nine sites were sampled on the Wisconsin River between river miles 3 and 307 during the 2005 sampling season (Figure 4). Of the twenty-nine target sites, seventeen were sampled during the day and twelve were sampled at night. Nighttime sampling was restricted to impoundments (Appendix 1).

2.1.4. Scioto River

The Scioto River is a sixth order tributary to the Ohio River, approximately 225 mi (364 km) in length and drains an area of 16,880 km². Mean discharge is 189 m³/s. It is contained entirely within Ohio, originating in the glacial till plains of the Central Lowland physiographic province of Ohio in Auglaize County flows to its confluence with the Ohio River at Portsmouth in Scioto County (White et al. 2005). It flows southeast across west-central Ohio, becoming entrenched in the sloping landscape. From Chillicothe downstream the river runs through the heavily forested Appalachian Plateaus physiographic province. Major tributaries to the Scioto River include Big and Little Darby creeks; large portions of which are designated as National Wild and Scenic Riverways. The Scioto River is shallow and generally sandy with some larger glacial till. The Scioto has not been heavily impounded with the exception of two places in Franklin and Delaware counties respectively, creating reservoirs for flood relief. Impacts from impoundments on the mainstem are low. However middle portions near the confluence with the Olentangy River exhibit impacts from increasing agriculture and urbanization (White et al. 2005).

Watershed land cover is largely agricultural. Rowcrops, forest and pasture/hay combine to comprise the majority of the total basin land cover. Riparian land cover is 62.2% agricultural and 28.6% forested. Human induced land use comprises 72.2% of the total watershed area and is primarily agricultural. The watershed is heavily impacted by rowcrops and pasture/hay, and is minimally impacted by industry and mining operations. The basin is largely rural. Residential areas represent roughly 3% of its spatial composition. The Scioto River is heavily impacted throughout its length. The Scioto River land cover map is located in Appendix 1.

A total of thirty sites were sampled on the Scioto River between river miles 1 and 150 during the 2005 sampling season (Figure 5). Of the thirty target sites, twenty-seven were sampled during the day and three were sampled at night. Nighttime sampling was restricted to impoundments (Appendix 1).

2.1.5. Minnesota River

The Minnesota River is seventh order stream and the first major tributary of the upper Mississippi River and increases its drainage area by nearly 50%. The river is approximately 330 mi (535 km) in length, lies entirely within the Central Lowland physiographic province and drains over one fifth of the state of Minnesota as well as small portions of South Dakota and northern Iowa for a total basin area of 27,030 km² (DeLong 2005). Mean discharge is 125 m³/s. The Minnesota River is minimally impounded and originates in a depression as Big Stone Lake and meanders southeasterly as a small through deep valleys. The river displays marked sinuosity as it moves along the valley floor, creating many backwaters and oxbows. At Mankato the Minnesota River turns sharply northeast and flows to its confluence with the Mississippi River near St. Paul. Nearly 95% of the basin is used for agriculture and the river is heavily impacted. The river is considered vulnerable to further degradation of water quality.

Watershed land cover is largely agricultural. Rowcrops and pasture/hay combine to comprise the majority of the total basin land cover. Riparian land cover is 72.4% agricultural and 10% forested. Human induced land use comprises 87.2% of the total watershed area and is primarily agricultural. The watershed is heavily impacted by rowcrops and pasture/hay, and is minimally impacted by mining and commercial industry. The basin is largely rural, as residential areas represent roughly 1% of its spatial composition. The Minnesota River is severely impacted throughout its length. The Minnesota River land cover map is located in Appendix 1.

A total of twenty-seven sites were sampled on the Minnesota River between river miles 21 and 300 during the 2006 sampling season (Figure 6.). Of the thirty target sites, twenty-seven were completed during the day. The remaining three, considered night sites by ORSANCO standards were omitted for logistical reasons (Appendix 1).

2.1.6. Muskingum River

The Muskingum River is a tributary to the Ohio River. Originating at the confluence of the Tuscarawas and Walhonding rivers at Coshocton in central Ohio, it is approximately 111 mi (179 km) in length and drains an area of 8051 mi² (13,043 km²). Physiographically it is located entirely within the Allegheny Plateau provinces, divided between the Muskingum-Pittsburgh and Ironton Plateaus (White et al. 2005). The Muskingum River flows generally southward towards its confluence with the Ohio River at Marietta in Washington County. The Muskingum River is fragmented by several low head dams and locks as the river was formerly an important commercial waterway. The riverbed is composed primarily of sandy substrates throughout. It is moderately impacted by agriculture and livestock. The Tuscarawas River is approximately 125 mi (201 km) in length and it is minimally impacted by impoundments and lies physiographically within the Western Allegheny Plain. The river flows in a southwestern direction through steep sloped valleys and has been impacted by agriculture and cattle farming. The Tuscarawas riverbed is comprised primarily of sandy to coarse substrates.

For the purposes of this study, the Muskingum and Tuscarawas rivers were considered a single entity, draining a total area of 20,817 km² and will henceforth be referred to as the Muskingum River. Watershed land cover is nearly equal with respect to both agriculture and forest. Rowcrops, forest and pasture/hay combine to comprise the majority of the total basin land cover. Riparian land cover is 44% agricultural and 42.2% forested. Human induced land use comprises 54.8% of the total watershed area and is primarily agricultural. The watershed is heavily impacted by rowcrops and pasture/hay, and is minimally impacted by mining. The basin is largely rural, as residential areas represent roughly 3% of its spatial composition. The Muskingum River is moderately impacted throughout its length. The Muskingum River land cover map is located in Appendix 1.

Surveys were conducted at a total of thirty sites during the 2006 sampling season (Figure 8.). Of the thirty target sites, twenty-one were completed during the day and the remaining nine were sampled at night. Nighttime sampling restricted to the Muskingum mainstem, downstream of Coshocton, OH (Appendix 1).

2.1.7. Illinois River

The Illinois River is a ninth order tributary to the Mississippi River originating at the confluence of the Des Plaines and Kankakee rivers southwest of Chicago. It is over 270 mi (439 km) in

length with a drainage area of 75,136 km² and is the largest river in Illinois. The Illinois River has a mean discharge of 649 m³/s and is located entirely within the Tilled Plains section of the Central Lowland physiographic province (DeLong 2005). The river flows from its origin southwesterly to its confluence with the Mississippi River. The Illinois River is navigable along its entire length and a nine foot channel is maintained by the U.S. Army Corps of Engineers. The main stem moderately impounded and is fragmented by five low-head navigational dams. The Illinois River is an important shipping channel and maintains a moderate to high degree of traffic. Nearly 90% of the basin is used for agriculture and the river is subsequently impacted. The Illinois River has been subject to biological invasion by two invasive species of carp, the silver (*Hypophthalmichthys molitrix*) and bighead (*Hypophthalmichthys nobilis*). Not only are these species remarkably fecund, but also exhibit spectacular breaching behavior in the presence of watercraft. This behavior has resulted in numerous injuries to boaters and makes the Illinois River a risky recreational waterway.

Watershed land cover is largely agricultural. Rowcrops, pasture/hay and forest combine to comprise the majority of the total basin land cover. Riparian land cover is 64.6% agricultural and 16.3% forested. Human induced land use comprises 85.3% of the total watershed area and is primarily agricultural. The watershed is heavily impacted by rowcrops and pasture/hay, and is minimally impacted by mining and commercial industry. The basin is largely rural. Residential areas represent roughly 4% of its spatial composition. The Illinois River is severely impacted throughout its length. The Illinois River land cover map is located in Appendix 1.

A total of thirty sites were sampled on the Illinois River between river miles 14 and 299 during the 2006 sampling season (Figure 7.). Of the thirty target sites, three were sampled during the day on the lower Des Plaines River above Dresden Dam, while the remaining twenty-seven were sampled at night, downstream of Dresden Dam on the Illinois River mainstem (Appendix 1).

2.2. SITE MAPS

2.2.1. St. Croix River (2004)

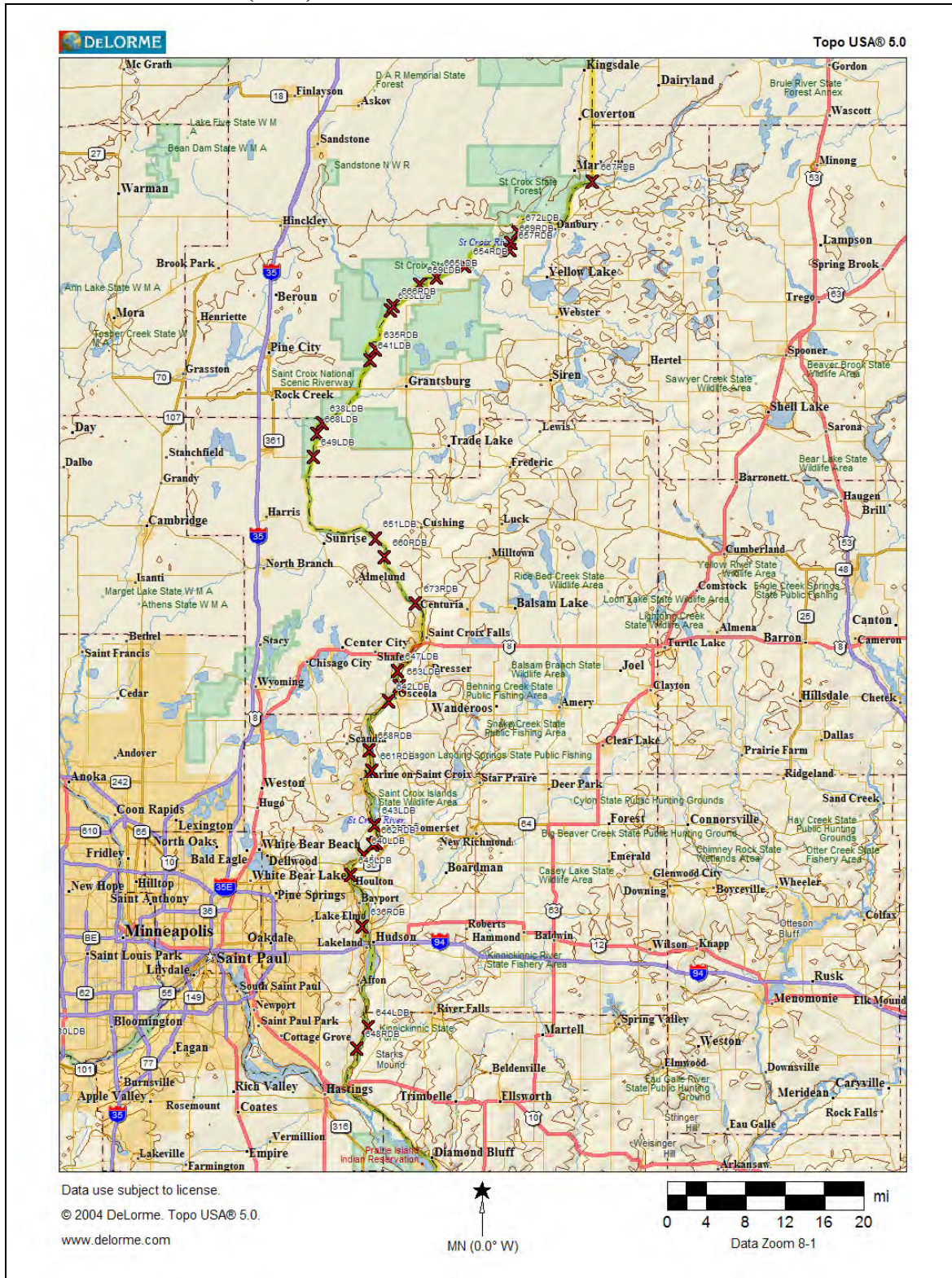


Figure 2. St. Croix River sites
2.2.2. Wabash River (2004)

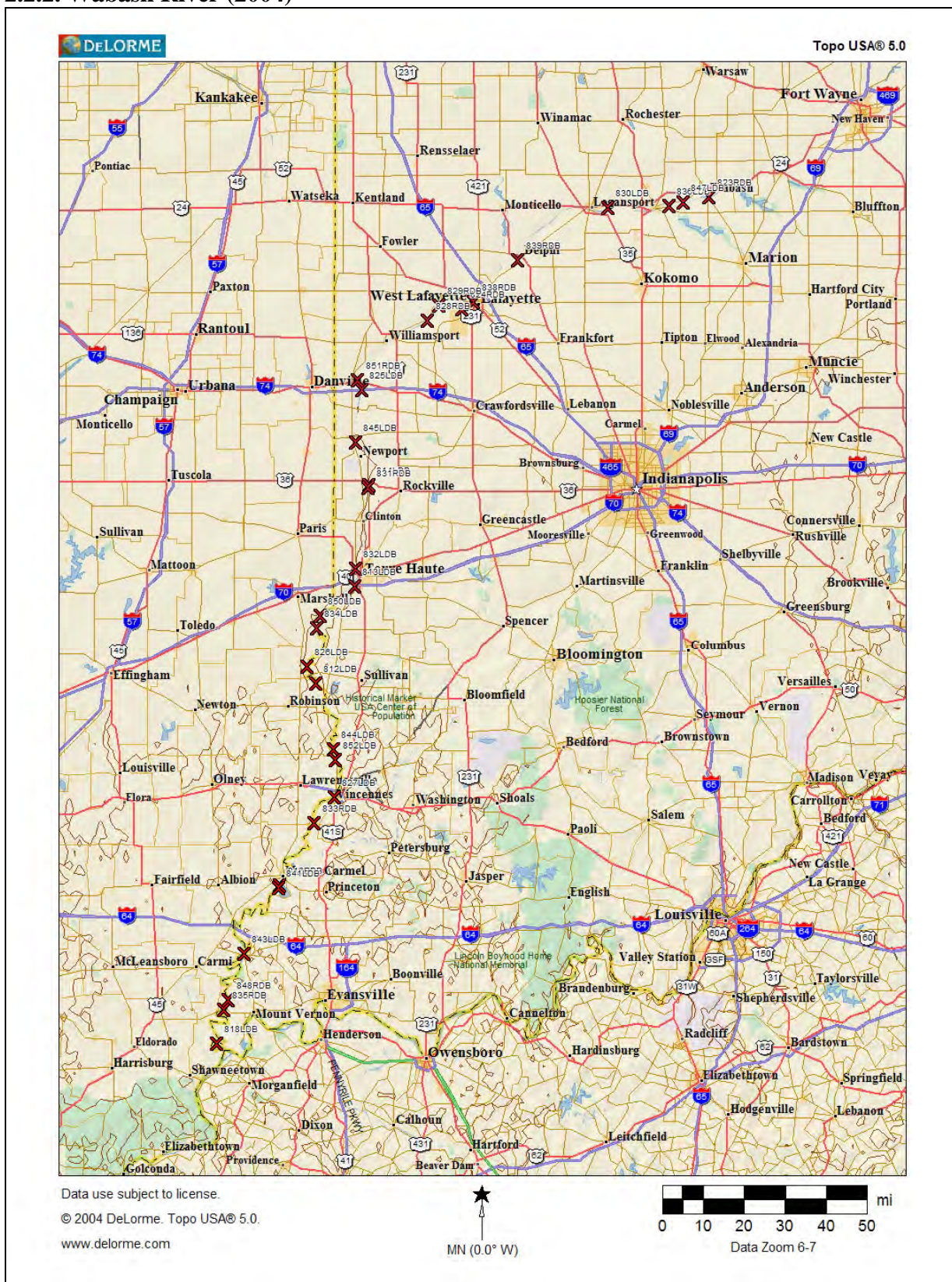


Figure 3. Wabash River sites
2.2.3. Wisconsin River (2005)

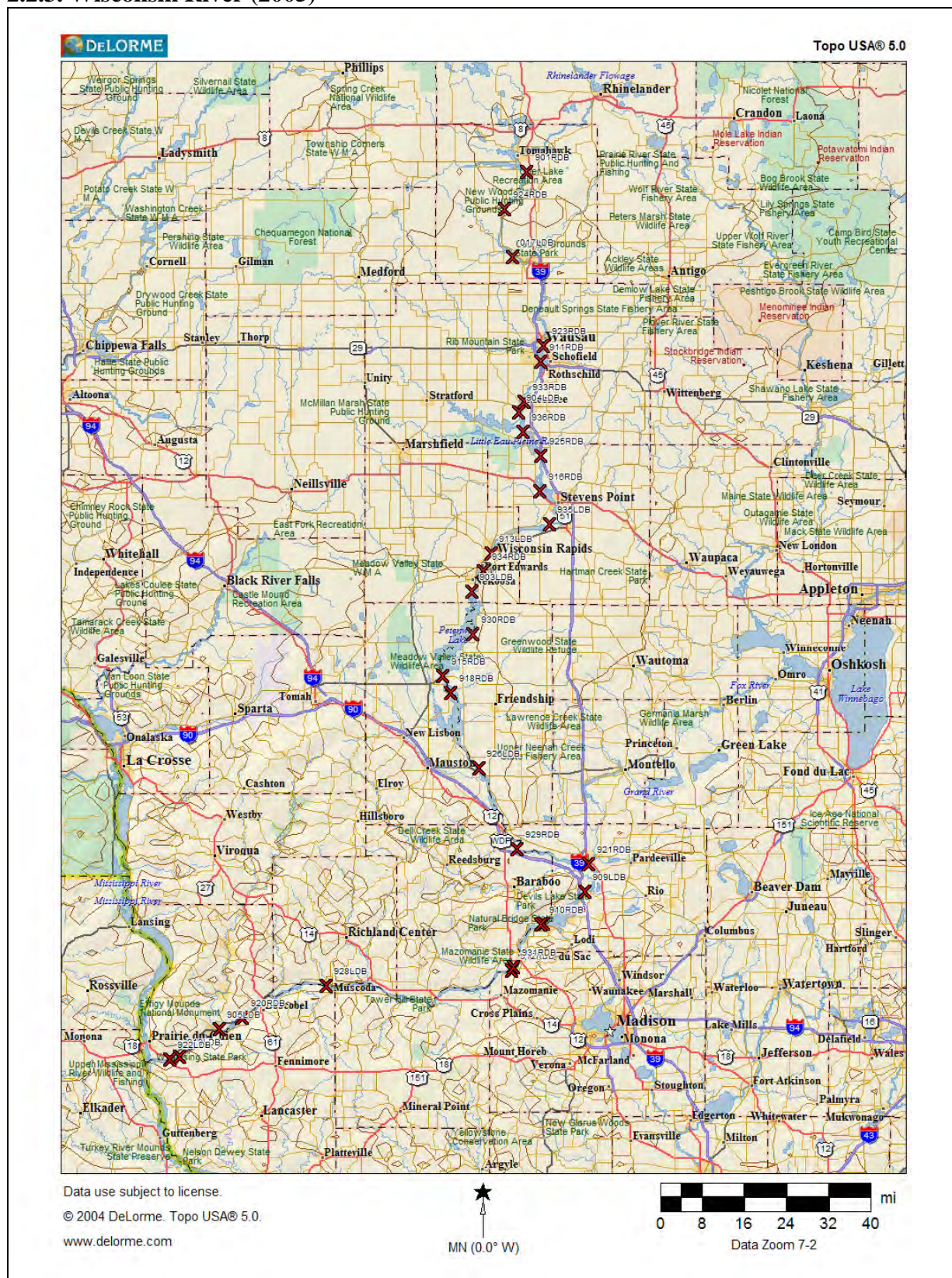


Figure 4. Wisconsin River sites
2.2.4. Scioto River (2005)

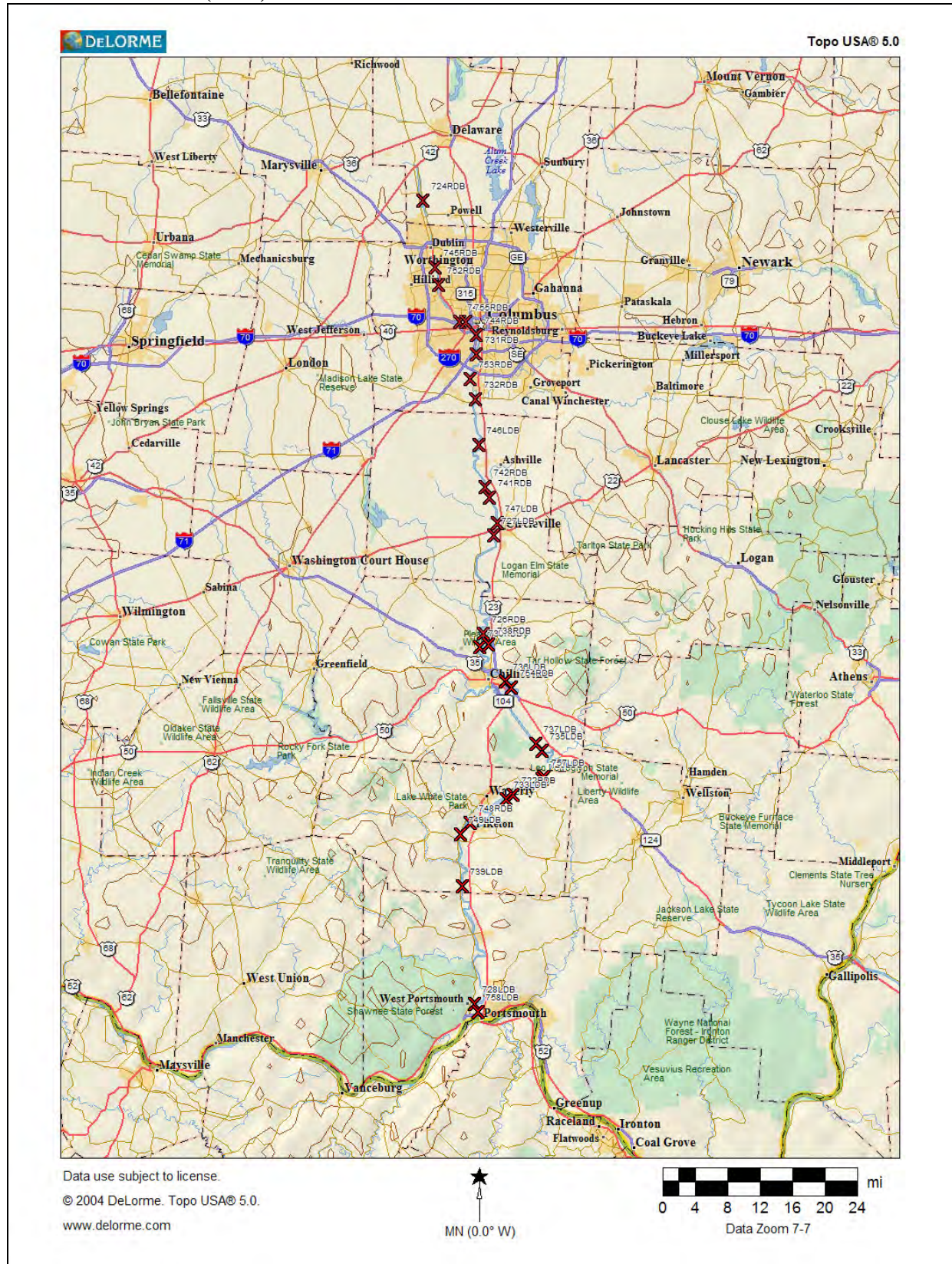
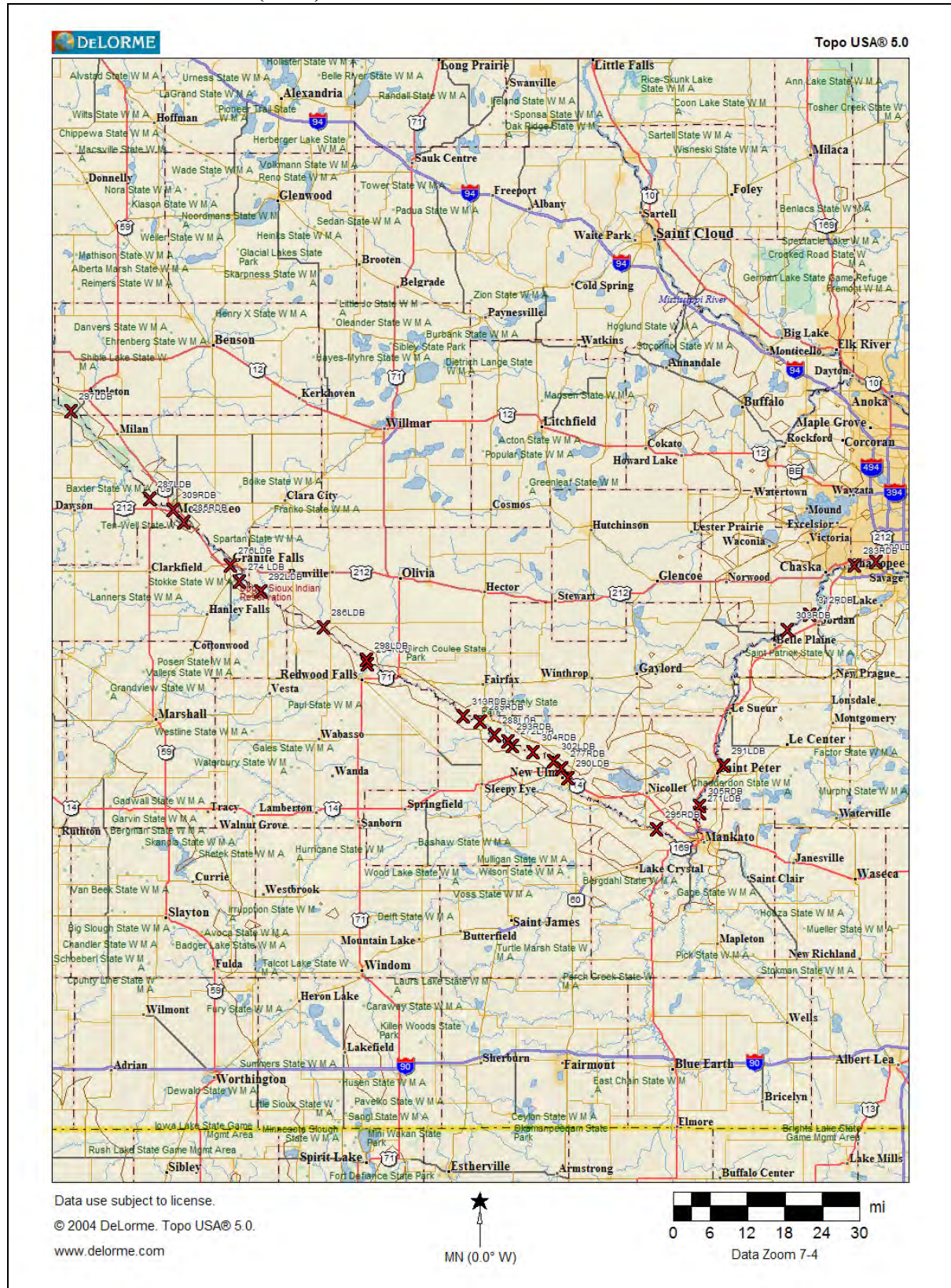


Figure 5. Scioto River sites
2.2.5. Minnesota River (2006)



2.2.6. Muskingum River (2006)

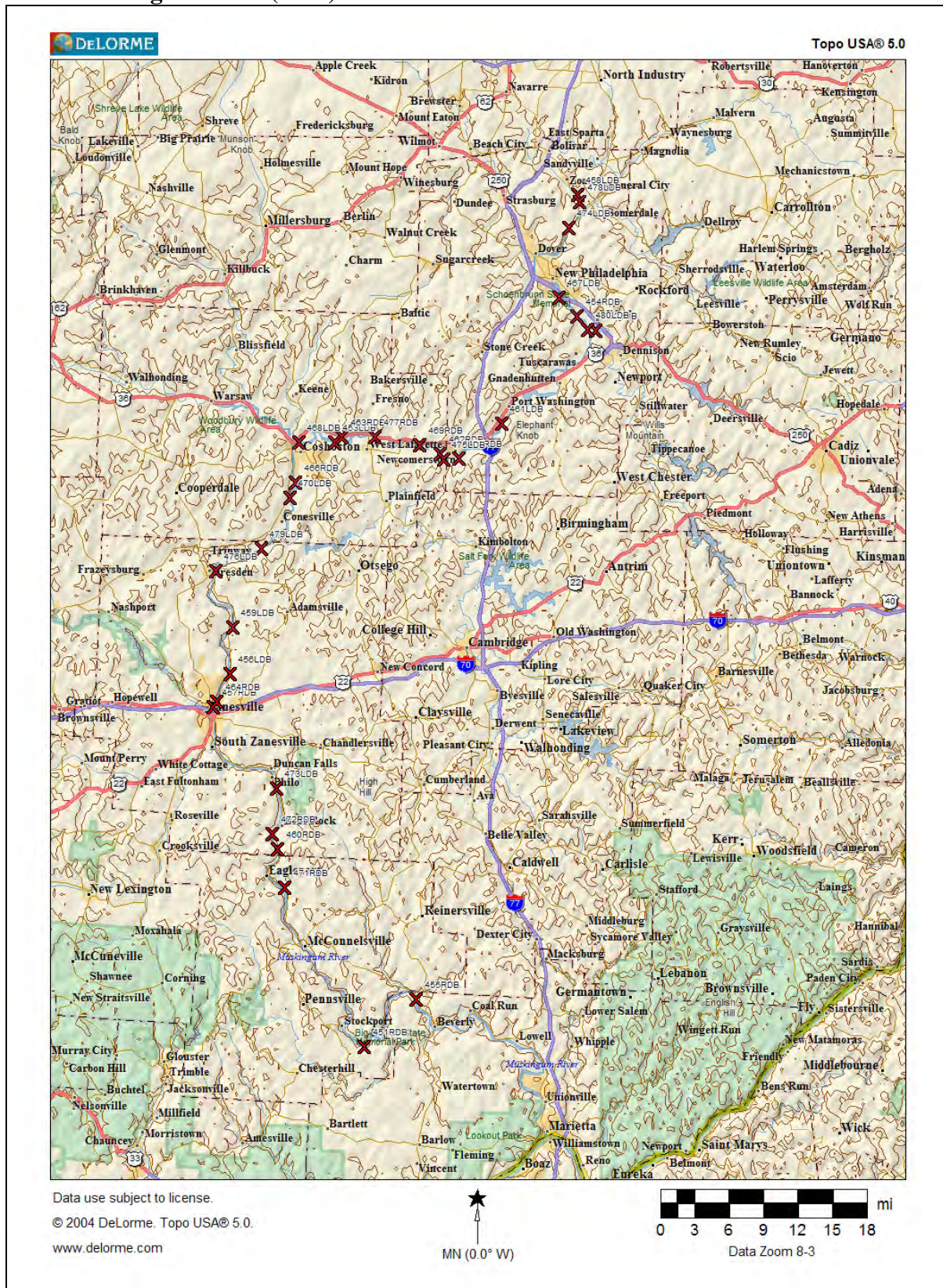


Figure 7. Muskingum River sites
2.2.7. Illinois River (2006)



Figure 8. Illinois River sites

2.3. SAMPLING EQUIPMENT/ PROTOCOLS

2.3.1. Electrofishing Procedure

The standard ORSANCO large river (non-wadeable) sampling protocol includes boat electrofishing and a habitat evaluation at each site. The methods and approaches described by Ohio EPA (1989) and Yoder and Smith (1999) for the collection of daytime samples and Emery et al. (2003) for the collection of nighttime samples were used to generate all fish data. Generally, daytime techniques were employed in shallower waters (less than 4m deep), required the use of a smaller boat, and were more frequently required in the upper reaches of the target rivers. Deeper waters required the use of a larger boat and were more frequently encountered in the lower reaches of the rivers or in impounded areas.

Site locations for this study were provided at latitude and longitude coordinates in decimal degree format and indicated the start or 'top' of each electrofishing zone. All site locations were randomly generated by the USEPA ORD in Corvallis, Oregon and are listed in Appendix 1.

The initial goal was to sample thirty sites along the length of each river included in this study. Site lists for each target river included thirty primary or 'target' sites and sixty 'overdraw' sites, each with a randomly designated bank. Site selection was achieved by making every attempt to sample each of the thirty primary sites. Site starting points were shifted as appropriate to ensure safety by avoiding restricted areas surrounding dams and power plants and other situations (physical impediments etc.) deemed by the crew leader as unsafe. Sites could be shifted 500 m upstream of the starting point or 'X', 500 m downstream of the 'X', and finally to the opposite target bank. This protocol was observed in each instance where a target starting point was not workable. In the event that any target site could not be appropriately shifted, it was omitted and overdraw sites were sampled, in order, until thirty sites were completed for each river.

A boat-rigged, pulsed D.C. electrofishing apparatus was the single gear employed throughout this study. The electrofishing platform consisted of 16' and 18' aluminum boats specifically constructed and modified for electrofishing. Electric current was converted, controlled, and regulated by Smith-Root 5.0 GPP alternator-pulsator that produced up to 1000 volts DC at 10-20 amperes depending on relative conductivity and power output. The latter was adjusted to the maximum range that could be produced given the relative conductivity of the water. This resulted in duty cycles of 50-100% in most cases. The pulse configuration consisted of a fast rise, slow decay wave that can be adjusted to 30, 60, or 120 Hz (pulses per second). Generally, electrofishing was conducted at 120 Hz. However, due to varying ambient conditions, other settings were used to ensure that the appropriate voltage and amperage output were maintained and fish were being effectively stunned. This was determined on a trial and error basis at the beginning of each boat electrofishing zone and the settings generally held for similar reaches of the same river. On the 16' boat, the electrode array consisted of four 8' long cathodes (negative polarity; 1" diameter flexible steel conduit) which were suspended from the bow and 5 anodes (positive polarity) suspended from a retractable aluminum boom that extended 2.75 meters in front of the bow. Each anode consisted of 3/8" woven steel cable strands (each 4' in length). These could be added, detached, and replaced as conditions changed. The width of the array was 0.9 meters. Anodes and cathodes were replaced when they were lost, damaged, or became worn. For the 18' boat, the boat hull, in conjunction with 32, 3/8" woven steel cable strands bolted to angle iron welded to the bow, served as cathodes. The anodes consisted of a pair of Smith-Root retractable fiberglass standard GPP booms each fitted with removable Smith-Root LPA-6 low profile 3/8" woven steel cable dropper arrays. Illumination for nighttime sampling was provided

by 12 volt DC automotive lights supplemented by auxiliary headlamps worn by the sampling crew (which consists of a driver and 2 netters) and hand-held DC powered lamps of at least 2,000,000 candle power.

Each sample site was navigated to via GPS. After the optimal voltage and amperage was achieved with the 5.0 GPP pulsator, the electrofishing boat was slowly and methodically maneuvered in a down-current direction along a 500 meter shoreline segment. The driver maneuvered in and around submerged cover to advantageously position the netter to pick up stunned and immobilized fish, while also adjusting the pulsator to maintain the maximum output, yet safe operational mode in terms of voltage range, pulse setting, and amperage. In areas with extensive woody debris and submergent aquatic macrophytes, it was usually necessary to maneuver the boat in and out of these “pockets” of habitat and wait for fish to appear within the netter’s field of view. In very shallow waters (< 2ft) during daytime sampling it was occasionally necessary for the driver to disengage the outboard motor and physically maneuver the boat in and out of riffles and other instream structure while wading behind the boat. While manipulating the watercraft by its transom the driver simultaneously controlled a ‘kill switch’. In these situations, one netter would stand in the water near the shore to scrape the substrate using a dipnet, while the other netter remained on the boat, capturing all stunned fish. During this procedure all crew members were outfitted with chest waders to insulate them from the electrical field.

In moderately swift to fast current the procedure was to electrofish with or slightly ahead of the current through fast water sections and then return upstream to more thoroughly sample eddies and side edges of the faster water. It was often necessary to pass over these swift water areas twice to ensure adequate sampling. Electrofishing efficiency was enhanced by keeping the boat and electric field moving with or at a slightly faster rate than the prevailing current velocity. This allowed the electrical field to remain vertically extended, as opposed to being collapsed against the bottom of the boat by the resistance of the current. In addition, fish are generally oriented against the current and must turn sideways or swim into the approaching electric field to escape. As such they are presented an increased voltage gradient making the fish more susceptible to the electric current. Sampling these areas in an upstream direction was avoided as this collapses the electrical field upwards against the boat, which significantly diminishes the effective size of the field. Based on visual observations and our experience, fish can avoid capture more easily when sampling against the current. Although sampling effort is measured by distance, the time fished was an important indicator of adequate effort. Time fished could legitimately vary over the same distance as dictated by cover, current conditions, and the number of fish encountered. In most cases, there was a minimum time spent sampling each zone regardless of the difficulty or size of the catch. Based on our experience this was generally in the range of 2500 seconds of electrofishing time (time during which current is actively applied to water) for 500 meters, but could range upwards to 3000-3500 seconds where there were extensive instream cover and slack flows. Time was recorded in seconds on the 5.0 GPP control box and recorded on each electrofishing data sheet.

Safety features included easily accessible toggle switches on the pulsator unit and next to the driver and a foot pedal switch operated by one of the netters. The netters wore jacket style personal floatation devices and rubber gloves. Each boat was fitted with a handrail behind which netters would operate. Appropriate modifications to this equipment were made throughout the duration of the project, including protective shields fitted to the handrail and a polycarbonate windshield. All modifications were made to ensure the safety of the field crew. Sampling was conducted between June 16 and October 30. However, we were aware of earlier fall cutoff dates where they have been demonstrated by the state agencies to be important.

Netters were required to wear polarized sunglasses during daylight to facilitate seeing stunned fish in the water during each daytime boat electrofishing run (not required for nighttime runs). Smith Root heavy duty dip nets with 2.5 m long fiberglass handles and 7.62 mm Atlas mesh knotless netting were used to capture stunned fish as they were attracted to the anode array and/or stunned. A concerted effort was made to capture every fish sighted by both the netters and driver. Since the ability of the netters to see stunned and immobilized fish was partly dependent on water clarity, sampling was conducted only during periods of “normal” water clarity and flows. Periods of high turbidity and high flows were avoided due to their negative influence on sampling efficiency. If high flow conditions prevailed, sampling was postponed until flows and water clarity returned to seasonal, low flow norms. Further details of sampling procedures are outlined in Appendix 2.

2.3.2. Field Sample Processing Procedures

Captured fish were immediately placed in an on-board live well for processing. Water was replaced regularly to maintain adequate dissolved oxygen levels in the water, reduce waste by-products, and minimize mortality. Aeration was provided to further minimize stress and mortality. Fish that were not retained for vouchers or for laboratory identification were released back into the water after they were identified to species, examined for external anomalies, weighed, and measured for total length. Every effort was made to minimize holding and handling times. Invasive alien species were kept and appropriately disposed of out of the water or as specified in the state collecting permits. The majority of captured fish were identified to species in the field; however, minnows and other small specimens were preserved for later laboratory identification to ensure both accurate counts and taxonomic evaluation. Any uncertainty about the field identification of individual fish also required their preservation for later laboratory identification, except for unusually large specimens that were photographed. Fish were preserved for future identification in buffered 10% formalin and labeled by date, river, collector(s) and geographic identifier (e.g., river mile, site number). Identification was required to the species level at a minimum and to the sub-specific level in certain instances if necessary. A number of regional ichthyology keys were used and included Page and Burr (1991), Trautman (1981), Lee et al. (1980), Etnier and Starnes (1993), and Tomelleri and Eberle (1990). Questions were pursued with the recognized taxonomical expert in each state.

The sample from each zone was processed by counting individuals and recording weights and total lengths by species. Total lengths of each specimen were recorded to the nearest 3 cm size class, with 0.1 cm to 3 cm representing size class 1, and so on. Fish weighing less than 1000 grams were weighed to the nearest gram on a spring dial scale (1000 x 2g) with those weighing more than 1000 grams weighed to the nearest 25 grams on a 12 kg spring dial scale (12 kg x 50 g). Scales were properly zeroed prior to each individual sampling run. Individuals of the same species within the same size class were often weighed together. If too many individuals of a given species were encountered to make individual weighing and measuring practical, mass weights were taken via a systematic subsampling process. Larval fish were excluded in the data, as these are not only difficult to identify, but offer questionable information to an assemblage assessment (Angermier and Karr 1986).

The incidence of external anomalies was recorded following procedures outlined by Ohio EPA (1989) and refinements made by Sanders et al. (1999). The frequency of DELT anomalies (deformities, eroded fins and body parts, lesions, and tumors) is an essential indicator of stress caused by chronic agents, intermittent stresses, and chemically contaminated sediments. The percent DELT anomalies is a metric in some of the large river fish assemblage assessments that have been developed across the U.S.

2.3.3. Habitat Evaluation

Prior to conducting electrofishing at each site, the field crew completed ORSANCO's Habitat Data Collection Protocol (2003) as outlined in Appendix 2. This procedure is a physical evaluation of the benthic macrohabitat features and immediate riparian characteristics within the designated sampling area. This is a thorough yet rapid evaluation technique employed by agencies for the purpose of developing expectation of site specific performance. Additional habitat characteristics were recorded using qualitative, observation based methods (Rankin 1989, 1995) under seasonal low flow conditions. Attributes of habitat included were substrate diversity and composition, degree of embeddedness, cover types and amounts, flow velocity, channel morphology, riparian condition and composition, and pool and run-riffle depths. Stream gradients were determined from USGS 7.5' topographic maps and water clarity was measured with a secchi disk. Water quality included basic field parameters such as temperature, dissolved oxygen, and conductivity. These were determined at each sampling location with portable meters and at fewer locations using continuous monitoring devices. This habitat evaluation provides ancillary benefit to the sampling crew by revealing various features within the sampling reach that must be included, but may not be considered upon initial visual inspection. These data facilitate thorough execution of the electrofishing protocol.

A qualitative habitat assessment using an appropriate modification of the Qualitative Habitat Evaluation Index (QHEI; Ohio EPA 1989; Rankin 1989) (Appendix 2) was completed by the crew leader after each sampling run was completed. The QHEI is a physical habitat index designed to provide an empirical, qualified evaluation of the lotic macrohabitat characteristics that are important to fish assemblages. The QHEI was developed within several constraints associated with the practicalities of conducting a large-scale monitoring program, i.e., the need for a rapid assessment tool that yields meaningful information and which takes advantage of the knowledge and insights of experienced field biologists who are conducting biological assessments. This index has been used widely outside of Ohio and similar habitat evaluation techniques are in widespread existence throughout the U.S. The QHEI incorporates the types and quality substrate, the types and amounts of instream cover, several characteristics of channel morphology, riparian zone extent and quality, bank stability and condition, and pool-run-riffle quality and characteristics. Slope or gradient is also factored into the QHEI score. We followed the specific guidance and scoring procedures outlined in Ohio EPA (1989) and Rankin (1989). A habitat assessment form was completed by the crew leader for each zone over the standard 500 meters of sampling distance (see Appendix 2).

2.3.4. Field Data Recording

Field data and observations were recorded on water resistant data sheets. Fish assemblage data including species, size class, numbers and weights by species and size class, external anomalies, chemical/physical data, site name and numeration, sampling crew membership, time of day, time sampled, distance sampled, and electrofishing unit settings and electrode configurations were recorded on the fish sampling data sheet (Appendix 2). The Qualitative Habitat Evaluation Index (QHEI), with appropriate modifications for large rivers, was also completed at each site on a habitat assessment data sheet (Appendix 2). Data sheets are retained by ORSANCO and MBI. Voucher specimens collected during the study were deposited at ORSANCO for a period of one year or permanently at the Ohio State University Museum of Biodiversity. ORSANCO voucher specimens were then moved to the Center for Ohio River Research and Education at the Thomas More College Ohio River Biological Field Station for storage/ archiving. As such they provide a permanent record. These vouchers served to validate new species distribution records and for

verification of questionable field identifications. Each set of vouchers were labeled with the same location data recorded on the field sheet and they are also denoted on the field sheet. All data were entered into an electronic data format maintained and supported by ORSANCO. At this time we are using a Microsoft Access database, which is translatable to spreadsheet formats such as Microsoft Excel.

2.4. ANALYTICAL METHODS

2.4.1. Data Compilation

Analyses were performed on electrofishing data from 206 sites spanning seven different rivers/watersheds. Habitat data were collected in accordance with the aforementioned protocols at 192 sites and QHEI data were collected at all 206. Nutrient data were collected at 103 total sites, excluding the Muskingum watershed.

All electrofishing data collected by ORSANCO and MBI underwent a QA/QC process during which voucher specimens were identified to species and all records were checked for errors and cross-checked against established distributional information and state and national threatened and endangered species lists. All data were entered into a Microsoft Access® database such that they could be queried and analyzed in Microsoft Excel® and other analytical packages. All fish data were archived at ORSANCO. Habitat data underwent QA/QC and were entered into a Microsoft Access® database and archived at ORSANCO. QHEI data were entered and archived at MBI. All data were archived in both hardcopy and electronic formats.

A literature review was necessary to properly classify species with respect to feeding guilds and tolerance levels. Proper calculations could therefore be performed on fish metrics that are sensitive to numbers of tolerant species or individuals. References include Halliwell et.al (1999), Goldstein and Simon (1999), and Ohio EPA (1987).

Nutrient data collected by USEPA underwent an exhaustive QA/QC process prior to transfer to ORSANCO. QC Acceptance ranges were: $\leq 10\%$ Relative Percent Difference (RPD) for duplicates, 90-110% recovery range for LFM (or spike) samples and QC check samples. LFM data was used for QC verification when spike analysis exhibited matrix interference. All data were within the established ranges, therefore all data was considered acceptable. Calibration curves displayed at least 0.99 r^2 .

2.4.2. Land Use

Primary land use data was developed for many watersheds, including those in this study, in 1992 by the U.S. Geological Survey (USGS) as part of the Multi-Resolution Land Characteristics (MRLC) Consortium. Land usage maps corresponding to the watershed for each of the seven targeted rivers were based on Landsat-5 digital imagery data and generated with ArcGIS® v9.0 by the USEPA National Exposure Research Lab (NERL) in Cincinnati, OH. In 1999, the MLRCC produced began production on a second-generation, comprehensive land cover database that became available in 2001. Land use type was delineated within each basin using three types of data: 1) normalized imagery for three time periods per path/row, 2) ancillary data, including a 30m Digital Elevation Model (DEM) derived into slope, aspect and slope position, 3) per-pixel estimates of percent imperviousness and percent tree canopy, 4) 29 classes of land cover data derived from the imagery, ancillary data, and derivatives, 5) classification rules, confidence estimates, and metadata from the land cover classification (Homer et al. 2004). These data

sources produced 19 classes of land cover which are represented in the seven watersheds included here. Land use coverage areas (km²) were developed for each watershed (Appendix 1). Land use percentage totals were compiled and underwent QA/QC by USEPA NERL.

2.4.3. Data Analysis

The principal analytical tools used in this project are those associated with conventional data and statistical analysis. These were performed on personal computers using relational databases such as Microsoft Access®, Excel® and various statistical and graphical packages. Maps were generated using DeLorme Topo USA® 5.0 and Arc GIS 9.0. For each data set from each river and each individual site, numerous transformations or parameters of the fish population data (metrics) were used to determine an estimate of condition.

Metric values were calculated for the purpose of index development and included various measures of species richness and relative abundance per site. The initial index used to estimate biological condition was the Modified Index of Well-Being (MIwb). Additionally, the Index of Centers of Density (ICD) (Patton, 2001) was calculated to assess fish assemblages within each river individually. Data collected from 206 sites across seven rivers was used to develop a regional (USEPA Region 5) multimetric index of biotic health following guidelines obtained via personal communication with Karen Blocksom (USEPA-NERL), Emery et al. (2003) and Lyons (2001). The purpose of index development was two-fold: to further characterize biological condition and to determine efficacy of a large, regional-scale index. It is important to note that assessment endpoints derived here will not be used to determine impairment of selected watersheds. Rather, index scores will be used strictly to describe biological quality within and across the seven rivers in this study. Furthermore, endpoints derived from this regional index will be compared to those derived from more localized IBIs, such as Lyons et.al (2001) that is currently employed in Wisconsin and Minnesota.

2.4.3.1. Metrics

For the purpose of developing estimates of biological condition and a multimetric index of biotic integrity, numerous aspects of the data, both abiotic (habitat and water quality characteristics) and biotic (fish population) data were compiled (Appendix 2).

2.4.3.2. Modified Index of Well-Being (MIwb)

The Modified Index of Well-Being (MIwb; Ohio EPA, 1987) was calculated for each sample. A modification of the Iwb originally developed by Gammon (1976), the MIwb incorporates numbers of individuals, biomass and the Shannon Diversity index (H') based on numbers and weight. Thirteen highly tolerant species are eliminated from the numbers and biomass components, but retained in the Shannon indices. This modification of the original Iwb has the effect of precluding the inappropriate inflation of scores at moderately degraded sites with high numbers of tolerant species. The MIwb is a relatively simple measure of assemblage health based on diversity and abundance data. The MIwb can be used in multiple geographic locations as it does not require site-specific or regional calibration. It is a relative measure of the diversity, evenness, and relative abundance of a sample, thus it is a logical choice to compare data within or across rivers. The MIwb (for 500m (.5km) sampling distance) and Shannon's H' formula follow:

$$MIwb = 0.5\ln N + 0.5\ln B + H'(\text{no.}) + H'(\text{wt.})$$

Where:

N = relative (number/kilometer) numbers of all species excluding those designated as highly tolerant (Appendix 3)

B = relative weight (kilograms/km) of all species - excluding those designated as highly tolerant

$H'(\text{no.})$ = Shannon Diversity index based on numbers (\log_e transformation)

$H'(\text{wt.})$ = Shannon Diversity index based on weight (\log_e transformation)

Shannon Diversity index:

$$H' = - \sum_{i=1}^S \frac{n_i}{N} \ln \frac{n_i}{N}$$

Where:

n_i = relative number or weight of the i th species

N = total number or weight of the sample

In a strictly mathematical sense, the MIwb has no ceiling with respect to maximum attainable score. In theory, as sampling at a particular site produces more species in evenly distributed numbers with likewise evenly distributed weights, the associated MIwb score will increase unimpeded. However, practical knowledge and historical collections reflect scoring limitations based on sampling methodology and geographical location. Generally speaking, sites with MIwb scores approaching values of 10 and higher are considered to be of very high quality.

2.4.3.3. Index of Centers of Density (ICD)

The Index of Centers of Density (ICD; Winston and Angermeier 1995) is a species diversity index that allows ranking of the relative conservation value of streams in order to prioritize conservation efforts (Bear 2006, Patton 2001). The ICD was modified by Patton in development of the MICD in order to incorporate both species richness and species densities.

As the MICD incorporates species richness, much like the MIwb, we chose to utilize the original ICD as opposed to its modified version. When employed in this capacity, the ICD complements the MIwb and avoids redundancy. The relative density of each species at each site was calculated according to current ICD protocol. Calculations for the ICD follow:

Relative density = Density of a species in a single 500m reach divided by the sum of density of the same species in all 500m reaches within a single river.

Higher scores relate to increasing density of less common, unique species at the individual site level within a single river. The utility of this index is most apparent when applied on a per river basis (Patton 2001). Where relative densities are derived from species densities of multiple rivers simultaneously, the ICD has the effect of introducing bias towards rivers that are inherently more speciose.

3.0. REGIONAL MULTIMETRIC INDEX

3.1. REGIONAL MULTIMETRIC INDEX DEVELOPMENT

A regional multimetric index was developed using a process laid out and refined by USEPA Office of Research and Development, National Exposure Research Laboratory (ORD-NERL) in 2006. We chose this method as it is based on established development protocols used in producing indices and is currently the most updated index development strategy. This development process is comprised of five components. These include:

- 1) Data Manipulation
- 2) Site Classification
- 3) Metric Screening
- 4) Metric Scoring
- 5) Validation

Each of these components has within it multiple steps. As abiotic and biological data are both incorporated, and specific to the target watershed or region, this process is in a sense self-calibrating with respect to the geographic location where it is to be applied. As a result, we were able to develop an index to function on a regional scale, and serve to meet our primary objective of estimating biological quality. It is important to note that in order for this process to be successful it requires a combination of statistics and professional judgment. However, in congruence with the recent shift away from the traditional 'IBI' nomenclature applied to multimetric indices, we have named our Region 5 index the Fish Assemblage Quality Index (FAQI). Although at least one of the rivers used in the data set had minimal disturbance and possessed or approached biological integrity, we made no reference to integrity in our naming scheme, although we believe doing so would have been in line with Karr's original intentions.

3.1.1. Data Manipulation

The data were separated into two sets, abiotic and biotic. The abiotic data set contained 30 variables, which included both simple water quality parameters (e.g. pH, dissolved oxygen, secchi, etc.) and instream habitat variables (e.g. depth, % woody cover, QHEI, etc.). The biotic data set was comprised of 113 fish population metrics which included counts, proportions, and biomass, subdivided by breeding guild, feeding guild, species group, etc.

3.1.2. Site Classification

Before further analyses of biotic data, the corresponding abiotic data were included in a principal components analysis (PCA) to distinguish minimally disturbed (reference) sites from low-quality (impaired) sites. For this to be done efficiently and effectively, some sites and individual abiotic variables were excluded from the analysis. We used case wise deletion of sites, which eliminated site records from the PCA if data was absent for any of the 30 abiotic variables. Individual abiotic variables were eliminated from the PCA if >50% of the sites had the same recorded value, or if 40% of the sites contained missing values for that particular variable. The remaining abiotic variables were included in the PCA analysis. Some variables were transformed to limit skew to 1 or less following suggestions by McCune & Grace (2002).

PCA axes 1 and 2 were plotted against each other to define a stressor gradient. Abiotic variable loadings were observed to determine which end of PCA Axis 1 corresponded with higher-quality

(↑QHEI, ↑pH, ↑Secchi, etc.) and which corresponds with lower-quality (↑Conductivity, ↑% Fines, etc.). This stressor gradient was then divided into quartiles. Those sites in the 25th percentile associated with higher-quality were classified as reference, while those in the 25th percentile associated with lower-quality were classified as impaired.

3.1.3. Metric Screening

Of the 113 candidate biotic metrics (Appendix 3) we incorporated only those that had a substantial range of values, were responsive to abiotic variables, and were not correlated with other metrics. Metrics were dropped due to restrictive range, i.e. $\geq 50\%$ of the values were the same. Richness metrics were eliminated if the range was ≤ 5 , and percent metrics were eliminated if the range was ≤ 10 . To examine the responsiveness of each metric, box plots were compared between reference and impaired sites. Metrics were eliminated if either median overlapped the interquartile range of the other box plot, indicating the metric was unresponsive to changes in the composite disturbance gradient. Finally, correlated metrics were eliminated to ensure that each new metric provides new information to the index. Spearman rank order correlations (r) were calculated between all possible subsets of the biotic metrics. If $|r| > 0.80$, the metric that showed the greatest responsiveness was kept, while the other was eliminated. If $|r| > 0.70$, a scatter plot was examined to determine if each metric exhibited a different response, (i.e., provided additional insight). If no additional insight could be gained then the previously described rules for elimination were followed. All remaining metrics were kept and used in the index.

3.1.4. Metric Scoring

To score each of the remaining metrics the biotic data set was divided into calibration and validation data sets. The calibration data set was used to determine the metric scoring equations, and the validation data set was used to confirm the usefulness of the resulting FAQI. To ensure each river was equally represented in both sets, 75% of the sites from each river were placed in the calibration data set; the remaining 25% were placed in the validation data set. Using only the calibration data set, metrics were scored on a continuous scale from 0 to 100. For each metric we set the 100 score threshold at the 95th percentile value, and the 0 score threshold to the 5th percentile value, according to the *CALU* method described by Blocksom (2003) (Figure 9). This method employs *Continuous* scaling (0-100) in lieu of *discrete* (1-3-5) scaling. All sites are used to set thresholds, rather than relying only on reference sites and *Upper* and *Lower* thresholds are set based on the statistical distribution of the data. Of the six scoring methods tested by Blocksom (2003), the *CALU* method performed well overall, based on six measures of method performance. These included the method's ability to discriminate reference from impaired condition, correlation with the stressor gradient, variability as reflected in CI length, signal to noise ratio and the number of condition classes that can be distinguished. Final FAQI scores were generated by summing the individual 12 metric scores for each site.

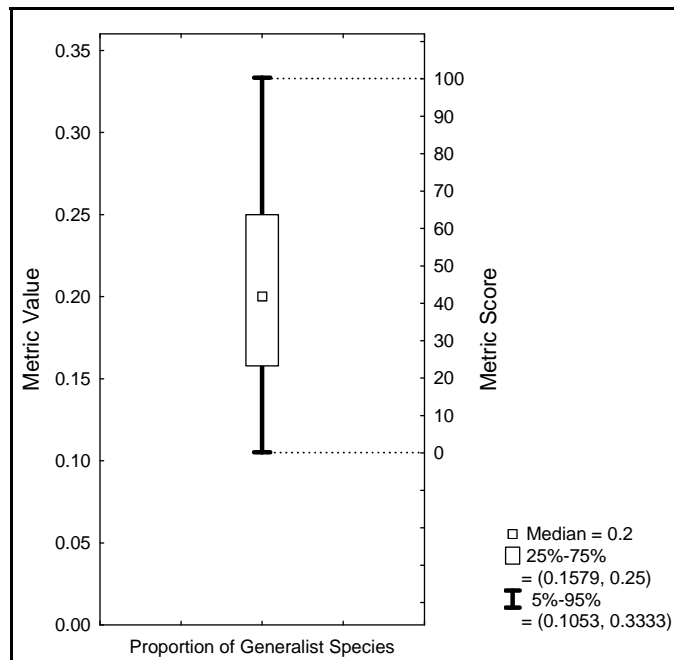


Figure 9. Example of how scoring thresholds were calculated for each of the biotic metrics in the Region V Fish Assemblage Quality Index (FAQI).

3.1.5. FAQI Validation

To validate that the FAQI was an adequate tool to assess large rivers in Region 5, FAQI scores were calculated for both calibration and validation sites. Scatter plots were generated for each data set, plotting FAQI score versus abiotic PCA Axis 1. The plots were then compared to determine if the distribution of the stressor gradient was similar between both the calibration and validation data sets. Poor consistency indicated a less than desirable option, while strong consistency indicated that the FAQI was a useful assessment tool.

3.1.6. FAQI Testing

To further test the usefulness of the FAQI, index scores were compared to other indices. A regression was conducted comparing FAQI scores to MIwb scores calculated for each of the 206 sites sampled. USEPA-ORD-NERL developed a preliminary index for benthic macroinvertebrates using data collected from all but one of the rivers sampled in this study, the Muskingum. To determine if both indices generally agreed across rivers, a regression was conducted on FAQI and LRBP scores. Lastly, FAQI scores were compared to state and local IBI scores for common sites. Indiana Department of Environmental Management (IDEM) provided scores for the Wabash River. Ohio EPA (OEPA) provided scores for the Scioto and Muskingum Rivers. Minnesota Department of Natural Resources (MDNR) provided scores for the Minnesota River and the St. Croix River, for which Minnesota Pollution Control Agency (MPCA) also provided scores. Wisconsin DNR (WDNR) provided scores for the Wisconsin River. All data provided by the individual state agencies were collected during the same year as sampling that was conducted by ORSANCO crews working under this project.

Of these IBI scores, only those which corresponded to a site which was sampled in the same year by a state agency, and fell within 500m upstream or downstream (See Section 2.3.1.) of one of the 206 REMAP sites were used in the regression. To further facilitate this comparison, FAQI scores were also generated for sites sampled by ORSANCO under the previous USEPA Methods Comparison Project. This was done because some of the Project sites, which incorporated rivers included the Region 5 REMAP were sampled during the same year as the state and local agencies. Thus the FAQI scores for the Methods Comparison Project sites provided a more accurate comparison than scores from REMAP sites, when REMAP sample years differed from those of the state agencies.

4.0. ADDITIONAL ANALYSES

4.1. River Analysis and Intra-river Comparisons

A cumulative distribution function (CDF) graph of FAQI scores was generated for each river to observe patterns in scoring. CDFs utilized sample weights provided as a function of the probability design used to draw (select) sampling sites. FAQI and abiotic PCA Axis 1 scores were plotted against the river miles of each river and compared to detect how well the index tracked the disturbance gradient observed in each river. MIwb, ICD, and FAQI scores were compared in a similar fashion to detect if these different biotic assessments generally agreed as to the quality of each site. Where data was available, FAQI and State IBI scores were compared at each river mile to determine how well the indices agreed as to the quality of each site.

4.2. Basin Analysis and Inter-river Comparisons

To observe patterns in scoring across rivers, CDF graphs of each of the seven rivers were plotted together. A PCA was conducted on the land type/use percentages obtained from USGS for each river basin (See Section 2.4.2.), and their resulting loadings on PCA Axis 1 were recorded. The land use PCA Axis 1 scores of each river were regressed against corresponding average abiotic PCA Axis 1 score. This was done to detect if small- scale (i.e., site level) instream habitat and water quality changes were correlated to broad scale changes in the land use of each basin. Average FAQI score for each river was also regressed against corresponding land use PCA Axis 1 scores to determine how the quality of the fish community was related to broad scale changes in the land use.

5.0. RESULTS & DISCUSSION

Results for this study are divided into three sections. The first section (5.1) includes all details specific to the Region 5 FAQI development. The second section (5.2) is separated into subsections specific to each river. Each of the seven subsections details findings and subsequent analyses, as well as exotic and threatened/endangered (T/E) and species distributions derived from current federal and individual state listings, all available in online resources. The third section (5.3) includes comparisons across all rivers in this study, combining results of the previous two sections. This will incorporate FAQI findings with sampling results from each survey.

5.1. REGIONAL MULTIMETRIC INDEX DEVELOPMENT

5.1.1. Site Classification

We collected a wide range of information used to describe abiotic condition (Table 1), including basic measures of physical water quality (temperature, D.O., pH, and conductivity), nutrient information and habitat (riparian and instream). Of the 30 candidate abiotic variables, only 11 were utilized in our PCA to define a stressor gradient to distinguish between reference and impaired sites (Table 1). We eliminated 13 variables because the same value occurred at more the 50% of the sites. An additional 6 were eliminated because more than 40% of the sites were missing values for those particular variables. Six of the final 11 abiotic variables were log-transformed to correct for slight skewness in their distributions. Of the 206 sampled sites, 78 sites were excluded because they contained missing values for one or more of the 11 abiotic variables; the remaining 128 sites were used in the PCA.

Table 1. Candidate abiotic variable list showing variables included and eliminated from the PCA.

| Abiotic Variables | Retained | Transformed | Eliminated | |
|--------------------------------|-----------------|---------------------|------------------------------|----------------------------------|
| | Included in PCA | Skewed Distribution | Same value $\geq 50\%$ sites | Missing values $\geq 40\%$ sites |
| <u>Water Quality</u> | | | | |
| pH | X | | | |
| Temp (°C) | X | | | |
| Dissolved Oxygen (mg/L) | X | log(obs) | | |
| Conductivity (µs/cm) | X | | | |
| Secchi (in) | X | log(obs) | | |
| <u>Instream Nutrients</u> | | | | |
| Total Phosphorus (mg/L) | | | | X |
| Total Kjeldahl Nitrogen (mg/L) | | | | X |
| Ammonia (mg/L) | | | | X |
| Nitrite/Nitrate (mg/L) | | | | X |
| <u>Instream Habitat</u> | | | | |
| QHEI | X | | | |
| % Boulder | | | X | |
| % Cobble | X | log(obs + 1) | | |
| % Gravel | X | | | |
| % Sand | X | | | |
| % Fines | X | log(obs + 1) | | |
| % Hardpan | | | X | |
| Avg Depth (ft) | X | log(obs) | | |
| % Sub Veg | | | X | |
| % Woody Cover | | | | X |
| % OverH Veg | | | | X |
| <u>Riparian Habitat</u> | | | | |
| % Trib | | | X | |
| % Barges | | | X | |
| % #Mooring Cells | | | X | |
| % Boats & Docks | | | X | |
| % Nat Forest | | | X | |
| % Resid/Lawns | | | X | |
| % Pasture | | | X | |
| % Crops/Ag | | | X | |
| % Industry | | | X | |
| % Concrete/Ramp | | | X | |
| TOTALS | 11 | 6 | 13 | 6 |

The resulting abiotic PCA axes 1 and 2 explained 29.1% and 18.5% of the total variance present in the data set, respectively. The variables that were most negatively correlated (i.e. $r \sim 0.5$) with Axis 1 were QHEI, Secchi, % cobble substrate, % gravel substrate, and pH (Table 2). The variables that were most positively correlated with Axis 1 were % fines present in the substrate and conductivity.

The development of a stressor gradient is a critical part of the index development process. The stressor gradient can be used to identify the best and worst sites and to document metric and index responsiveness to changes in physical and chemical habitat quality. As PCA Axis 1 explained the largest proportion of the variance among all sites, it was used to define our stressor gradient and identify a group of 'reference' sites and 'impaired' sites.

Table 2. Loadings of each abiotic variable on PCA Axis 1.

| Abiotic Variable | Correlation (r) |
|-----------------------|-----------------|
| QHEI | -0.795 |
| log(Secchi) | -0.715 |
| log(%Cobble+1) | -0.694 |
| %Gravel | -0.575 |
| pH | -0.504 |
| %Sand | 0.162 |
| Temperature | 0.220 |
| log(Dissolved Oxygen) | 0.250 |
| log(Depth) | 0.300 |
| Conductivity | 0.463 |
| log(%Fines+1) | 0.742 |

Variable values associated with good water and fish habitat quality correlated most strongly on the negative side of Axis 1 and the sites that fall at or below the 25th percentile were defined as reference (Figure 10). The sites at or below the 75th percentile on Axis 1 were defined as impaired.

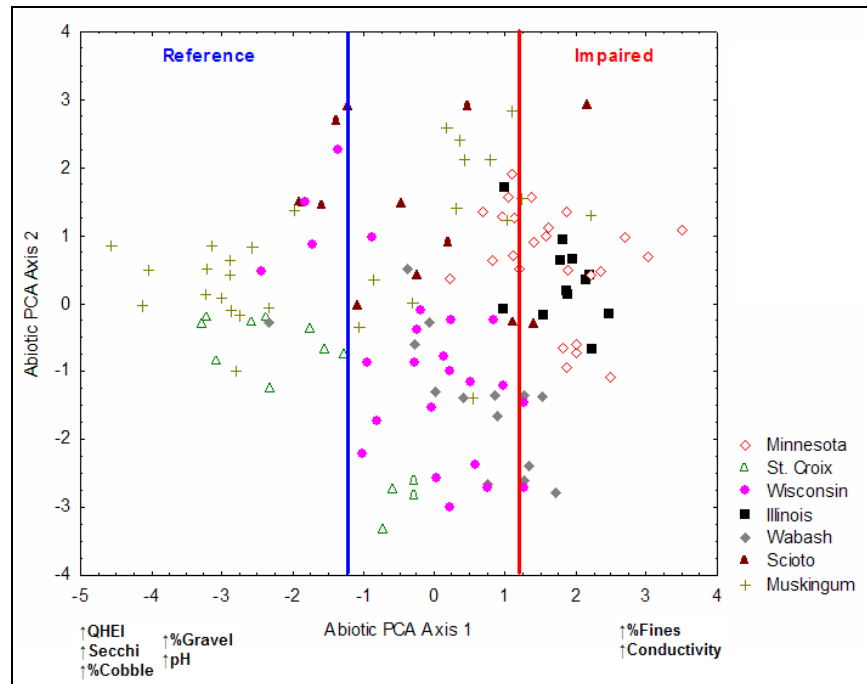


Figure 10. Stressor gradient used to define reference and impaired sites (labeled by river). Abiotic variables loading heavily on PCA Axis 1 are also labeled.

5.1.2. Metric Screening and Scoring

Of the 113 candidate biotic metrics only 12 were used in calculating a final FAQI score for each site (Table 3). We eliminated 68 metrics due to limited ability to discriminate between reference and impaired sites. An additional 30 metrics were eliminated because they were redundant with other metrics ($r > 0.70$), and 3 metrics were eliminated due to restricted ranges. For each of the final 12 metrics a scoring scale from 0 to 100 was generated using the CALU method (Blocksom, 2003), thus the maximum score achievable by a site was 1200.

Table 3. Candidate biotic metric list showing candidate metrics for the FAQI (bolded metrics were included in the FAQI, reason for elimination indicated).

| Metric | Definition | Retained | Reason for Elimination | | |
|---------------------|--|--------------------|------------------------|------------------------|------------|
| | | Final FAQI metrics | Limited Range | Limited Responsiveness | Redundancy |
| Ind | Total number of individuals captured | X | | X | |
| Ind-X | Total number of individuals excluding exotics | | | X | |
| Ind-H | Total number of individuals excluding hybrids | | | X | |
| Ind-T | Total number of individuals excluding tolerant individuals | | | | |
| Tot Kg | Total biomass of all individuals (kg/ind) | | | X | |
| Tot kg/Ind | Average biomass per individual (kg/ind) | | | X | |
| DELTs | Number of individuals with a deformity, erosion, lesion, and/or tumor | | | X | |
| Prop DELTs | Proportion of all individuals with a deformity, erosion, lesion, and/or tumor | X | | X | X |
| #SimpLiths | Number of Simple Lithophillic individuals | | | | |
| Sp | Total number of species captured including those only classified to genus | | | | |
| Unique Sp | Total number of unique species captured excluding those only classified to genus | | | | |
| #X | Number of exotic individuals | X | | X | |
| Prop #X | Proportion of all individuals that were exotic | | | X | |
| X_Sp | Number of exotic species | | | X | |
| Prop X_Sp | Proportion of unique species that were exotic | | | | |
| X kg | Total biomass of all exotic individuals (kg/ind) | | | X | |
| X kg/Ind | Average biomass per exotic individual (kg/ind) | | | X | |
| #H | Number of hybrid individuals | | X | X | |
| Prop #H | Proportion of all individuals that were hybrids | | | | |
| H_Sp | Number of hybrid species | | | X | |
| Prop H_Sp | Proportion of unique species that were hybrid | | | X | |
| H kg | Total biomass of all hybrid individuals (kg/ind) | | | X | |
| H kg/Ind | Average biomass per hybrid individual (kg/ind) | | | X | |
| #T | Number of tolerant individuals | X | | | X |
| Prop #T | Proportion of all individuals that were tolerants | | | | |
| T_Sp | Number of tolerant species | | | X | |
| Prop T_Sp | Proportion of unique species that were tolerant | | | | |
| T kg | Total biomass of all tolerant individuals (kg/ind) | | | X | |
| T kg/Ind | Average biomass per tolerant individual (kg/ind) | | | X | |
| #Int | Number of intolerant individuals | X | | | X |
| Prop #Int | Proportion of all individuals that were intolerants | | | | |
| Int_Sp | Number of intolerant species | | | | |
| Prop Int_Sp | Proportion of unique species that were intolerant | | | | |
| Int kg | Total biomass of all intolerant individuals (kg/ind) | | | | |
| Int kg/Ind | Average biomass per intolerant individual (kg/ind) | | | X | |
| #R Suck | Number of round-bodied sucker individuals | X | | | X |
| Prop #R Suck | Proportion of all individuals that were round-bodied suckers | | | | |
| R Suck_Sp | Number of round-bodied sucker species | | | X | |

| Metric | Definition | Retained | Reason for Elimination | | |
|---|---|--------------------------|------------------------|----------------------------|----------------------|
| | | Final FAQI metrics | Limited Range | Limited Responsiveness | Redundancy |
| Prop R Suck_Sp R Suck kg RS kg/Ind | Proportion of unique species that were round-bodied suckers Total biomass of all round-bodied sucker individuals (kg/ind) Average biomass per round-bodied sucker individual (kg/ind) | | | X X | X |
| #DB Suck Prop #DB Suck DB Suck_Sp Prop DB Suck_Sp DB Suck kg DBS kg/Ind | Number of deep-bodied sucker individuals Proportion of all individuals that were deep-bodied suckers Number of deep-bodied sucker species Proportion of unique species that were deep-bodied suckers Total biomass of all deep-bodied sucker individuals (kg/ind) Average biomass per deep-bodied sucker individual (kg/ind) | X | | X X X | X X |
| #Cent Prop #Cent Cent's Prop Cent_Sp Cent kg Cent kg/Ind | Number of centrarchid individuals Proportion of all individuals that were centrarchids Number of centrarchid species Proportion of unique species that were centrarchid Total biomass of all centrarchid individuals (kg/ind) Average biomass per centrarchid individual (kg/ind) | | | X X X X | X X |
| #GR Prop #GR Grasp Prop Grasp GR kg GR kg/Ind | Number of great river individuals Proportion of all individuals that were great river individuals Number of great river species Proportion of unique species that were great river species Total biomass of all great river individuals (kg/ind) Average biomass per great river individual (kg/ind) | | | X X X X X X | |
| #Darter Prop #Darter Darter's Prop Darter's Darter kg Dart kg/Ind | Number of darter individuals Proportion of all individuals that were darters Number of darter species Proportion of unique species that were darters Total biomass of all darter individuals (kg/ind) Average biomass per darter individual (kg/ind) | X | | X X | X X X |
| #Carmi Prop #Carmi Carnies Prop Carnies Carni kg Carni kg/Ind | Number of carnivore individuals Proportion of all individuals that were carnivores Number of carnivore species Proportion of unique species that were carnivores Total biomass of all carnivore individuals (kg/ind) Average biomass per carnivore individual (kg/ind) | X | | | X X X X |
| #Pisc Prop #Pisc Pisc_Sp Prop Pisc_Sp Pisc kg Pisc kg/Ind | Number of piscivore individuals Proportion of all individuals that were piscivores Number of piscivore species Proportion of unique species that were piscivores Total biomass of all piscivore individuals (kg/ind) Average biomass per piscivore individual (kg/ind) | | | X X X X X | |
| #C+Pisc | Total number of individuals classified as a carnivore or piscivore | | | | X |

| Metric | Definition | Retained | Reason for Elimination | | |
|----------------|--|--------------------------|------------------------|---------------------------|------------|
| | | Final FAQI metrics | Limited Range | Limited Responsiveness | Redundancy |
| Prop #C+Pisc | Proportion of all individuals that were either carnivore or piscivore | | | | X |
| C+Pisc_Sp | Total number of carnivore and piscivore species | | | | X |
| Prop C+Pisc_Sp | Proportion of unique species that were either carnivores or piscivores | | | X | |
| C+Pisc kg | Total biomass of all carnivore and piscivore individuals (kg/ind) | | | | X |
| C+Pisc kg/Ind | Average biomass per individual classified as a carnivore or piscivore (kg/ind) | | | X | |
| #Detr | Number of detritivore individuals | | | X | |
| Prop #Detr | Proportion of all individuals that were detritivores | | | X | |
| Detr_Sp | Number of detritivore species | | | X | |
| Prop Detr_Sp | Proportion of unique species that were detritivores | | | X | |
| Detr kg | Total biomass of all detritivore individuals | | | X | |
| Detr kg/Ind | Average biomass per detritivore individual (kg/ind) | | | X | |
| #Gen | Number of generalist individuals | | | X | |
| Prop #Gen | Proportion of all individuals that were generalists | | | X | |
| Gen_Sp | Number of generalist species | | | X | |
| Prop Gen_Sp | Proportion of unique species that were generalists | X | | | |
| Gen kg | Total biomass of all generalist individuals (kg/ind) | | | X | |
| Gen kg/Ind | Average biomass per generalist individual (kg/ind) | | | X | |
| #Herb | Number of herbivore individuals | | | | X |
| Prop #Herb | Proportion of all individuals that were herbivores | X | | | |
| Herb_Sp | Number of herbivore species | | | X | |
| Prop Herb_Sp | Proportion of unique species that were herbivores | | | | X |
| Herb kg | Total biomass of all herbivore individuals (kg/ind) | | | | X |
| Herb kg/Ind | Average biomass per herbivore individual (kg/ind) | | | X | |
| #Invert | Number of invertivore individuals | | | X | |
| Prop #Invert | Proportion of all individuals that were invertivores | | | X | |
| Invert_Sp | Number of invertivore species | | | | X |
| Prop Invert_Sp | Proportion of unique species that were invertivores | | | X | |
| Invert kg | Total biomass of all invertivore individuals (kg/ind) | X | | | |
| Invert kg/Ind | Average biomass per invertivore individual (kg/ind) | | | X | |
| #Plank | Number of planktivore individuals | | | X | |
| Prop #Plank | Proportion of all individuals that were planktivores | | X | | |
| Plank_Sp | Number of planktivore species | | | X | |
| Prop Plank_Sp | Proportion of unique species that were planktivores | | X | | |
| Plank kg | Total biomass of all planktivore individuals (kg/ind) | | | X | |
| Plank kg/Ind | Average biomass per planktivore individual (kg/ind) | | | X | |
| TOTALS | | 12 | 3 | 68 | 30 |

5.1.3. FAQI Validation

The scatter plot of the calibration data set, which included 154 sites (24 reference, 23 impaired, and 107 other), revealed an inverse relationship between FAQI scores and abiotic PCA Axis 1 score (i.e., a positive relationship between FAQI scores and water/habitat quality, Figure 11). A scatter plot of the same comparison for the validation data set, which included 52 sites (8 reference, 8 impaired, and 36 other), revealed a very similar relationship (Figure 11). The similarity of relationship for the validation data indicates that scoring thresholds are reasonable for this regional data.

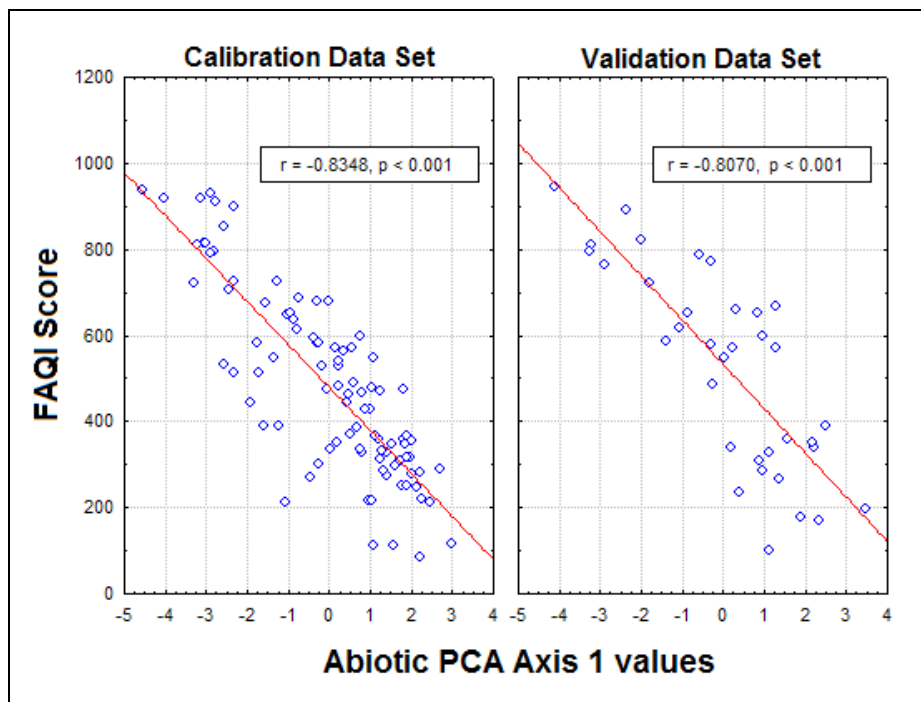


Figure 11. FAQI score plotted against the abiotic PCA Axis 1 score, divided into the calibration and validation data subsets.

The index scores at reference sites were significantly ($p < 0.01$, Mann-Whitney U-test) higher than scores at impaired sites for both the calibration and validation data sets (Figure 12). Overlap between scores from the reference and impaired sites was minimal for the calibration data set and did not occur with the validation data set.

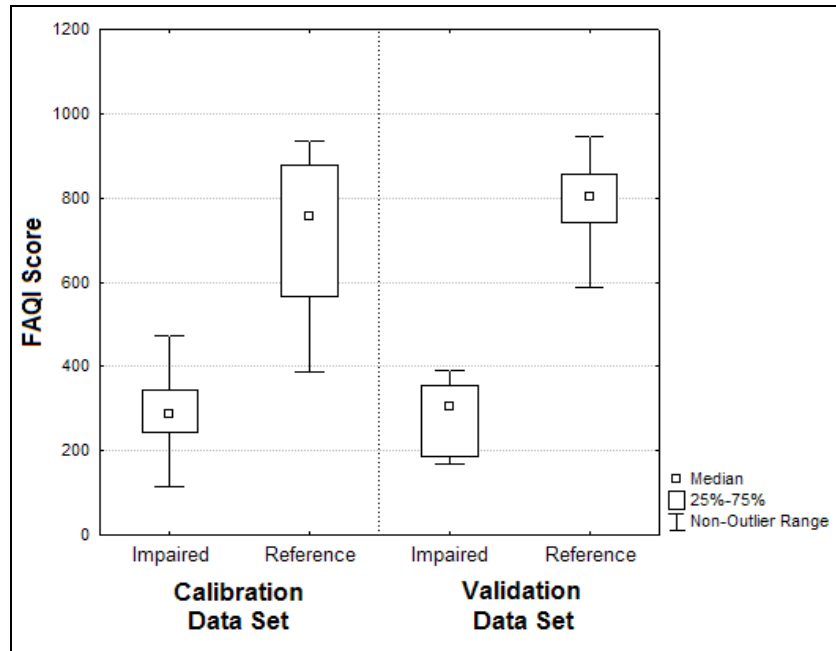


Figure 12. Ranges of scores for reference and impaired sites used to develop and validate the FAQI.

5.1.4. FAQI TESTING

When comparing results from our newly developed index to other, more well-established measures of fish community condition, we found general agreement with each. Fish Assemblage Quality Index (FAQI) scores for all of the rivers were positively correlated with corresponding MIwb scores ($r = 0.58$, $p < 0.001$, Figure 13). Although functionally, the MIwb is quite different from traditional IBI's and from our index, its responsiveness is well documented and it is in use by at least one Region 5 state agency. FAQI score was also positively correlated with *DRAFT* benthic macroinvertebrate index scores ($r = 0.73$, $p < 0.001$, Figure 14) generated by USEPA-NERL. There seems to be very strong agreement between the two indices. Combining both newly developed assessment tools would provide a dual indicator approach, although one could argue that with such agreement, the need for two indicators is not warranted and the justification for choosing one or the other of the indicators exists. However, the authors agree that combining assessment results from two separate biological indicators, each with varying tolerances and responsiveness, is not redundant and would elevate the credibility of any assessment of biological condition.

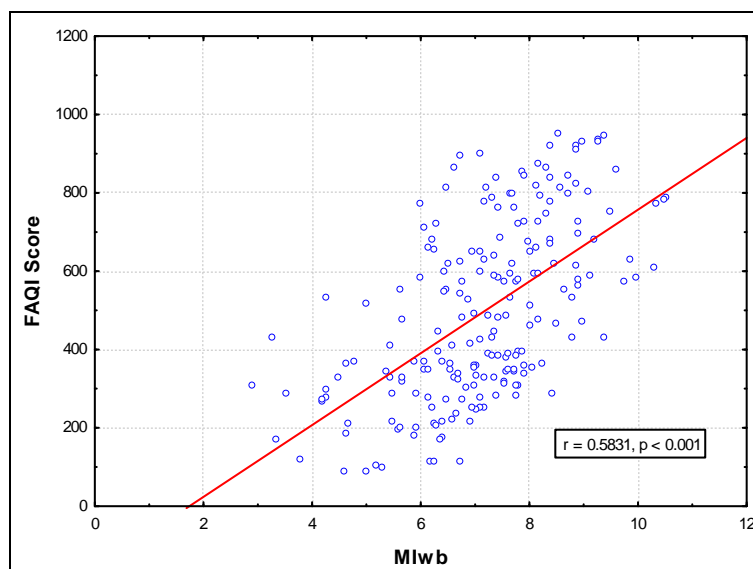


Figure 13. FAQI and Modified Index of Well-Being (MIwb) scores for the 206 sites sampled. Red trend line = regression line (r value shown).

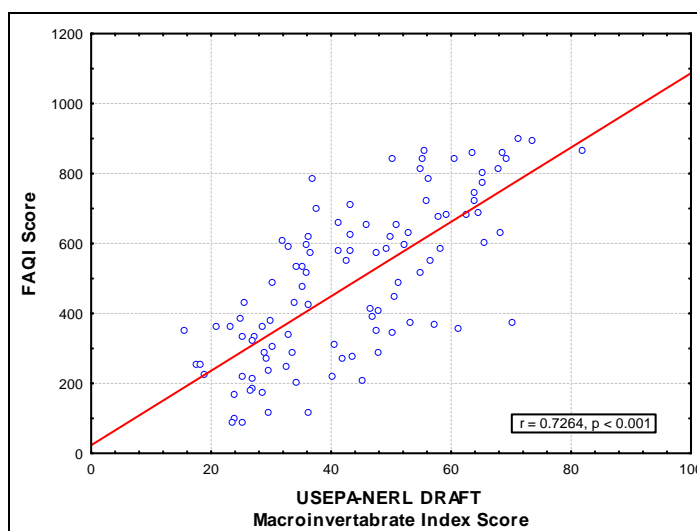


Figure 14. FAQI and DRAFT benthic macroinvertebrate index scores for the 103 common sites sampled by ORSANCO and USEPA-NERL, respectively. Red trend line = regression line (r value shown).

FAQI scores were found to also be positively correlated with state agency IBI scores ($r = 0.63$, $p < 0.001$), but were consistently lower than the states' scores (Figure 15). As stated earlier, the sites used in the comparison were sampled once by the crews collecting data under this project. Those data were used (in part) to develop the regional FAQI. On a separate date, within the same year, a state agency crew sampled the same site using their collecting technique and ran their version of the IBI on their data.

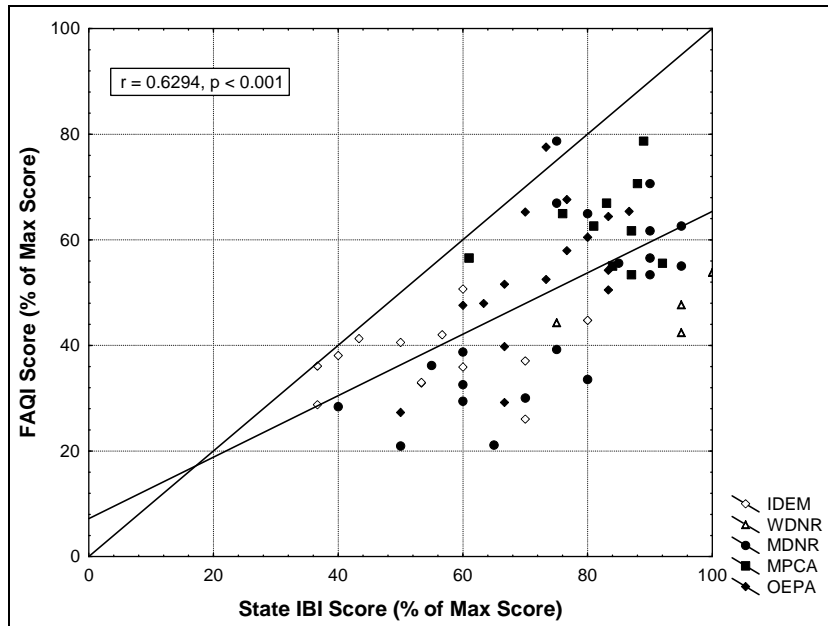


Figure 15. FAQI scores for the 63 common sites sampled by ORSANCO and various state agencies (labeled), respectively. Black trend line = 1:1 ratio. Red trend line = regression line (r value shown).

We hypothesize that the reason for the discrepancy between the state IBIs and the regional index is in part due to the effects of scale compression/expansion and residual effects on the abiotic range of condition used to establish thresholds. Figure 16 below displays the overall range of abiotic condition within each individual river and across the entire study area, as captured by PCA Axis 1 (including elements of water chemistry, physical water quality, instream and riparian habitat). Developing an index within a limited range of abiotic conditions significantly changes the thresholds established to identify ‘good’ or ‘poor’ conditions.

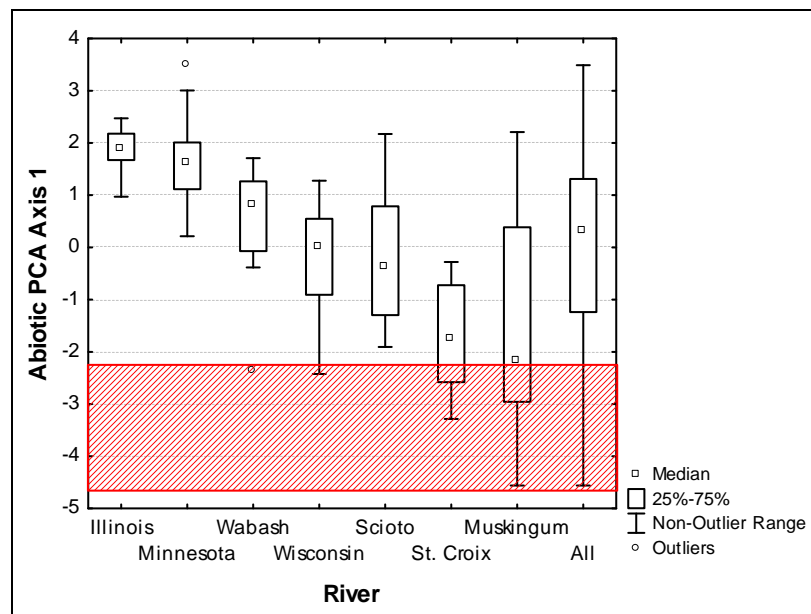


Figure 16. Plot showing the range of abiotic condition per river. The shaded area covers the range of condition used to identify reference sites.

Planners developing strategies for broad-scale assessments such as the National Survey of Non-wadeable Streams and Rivers, should be aware of this tendency, but should also be encouraged by the possibilities exhibited by this study. It is possible to develop assessment tools for broad geographic and abiotic ranges which are still responsive to disturbance, although somewhat less sensitive than tools developed at reduced scales, and provides information relevant to the management of these waters.

We suggest that future efforts be undertaken to further explore the data generated by this project and that additional projects be funded that explore the effects of increasing spatial scale and range of abiotic conditions.

5.2. INDIVIDUAL RIVER RESULTS

5.2.1. ST. CROIX RIVER

Between June and September 2004, electrofishing and habitat data were collected at 30 sites between river miles 4 and 129. River miles begin at the confluence of the St. Croix River, increasing towards its source. Of the 30 completed sites, 11 were sampled at night and 19 were sampled during the day. During the same index period, water chemistry and nutrient data were collected by USEPA at 20 overlapping sites.

5.2.1.1. Habitat / Water Quality Summary

Intensive physical habitat survey data taken from each of the thirty electrofishing sites revealed benthic substrate composition to be dominated by sand (67%). Coarser substrates combined to comprise 30% of the substrate (Figure 18), and were the dominant substrate in sites near the mouth and mid-upper reaches of the river (Figure 19). Fines and hardpan comprised 3% and 0% respectively (Figure 18). Submerged aquatic vegetation was present at 47% of the sites. Overhanging vegetation and in-stream woody cover were present at 80% and 73% of the sites respectively (Appendix 5). QHEI, water quality parameters, and nutrient data were collected when possible. Data gaps are attributable to equipment/ calibration failure. The average (SE) QHEI score for the St. Croix River was 72.5 (1.34) (Table 6). Scores varied slightly across sites, with higher scores in the mid-upper reaches (Figure 20). Average pH was 7.95 (0.10). Temperature averaged 19.89°C (0.63), and dissolved oxygen content averaged 13.64 mg/L (1.26). Conductivity was relatively low with an average value of 151.81µs/cm (6.66). Secchi depths averaged 50.31 inches (2.85) (Appendix 5).

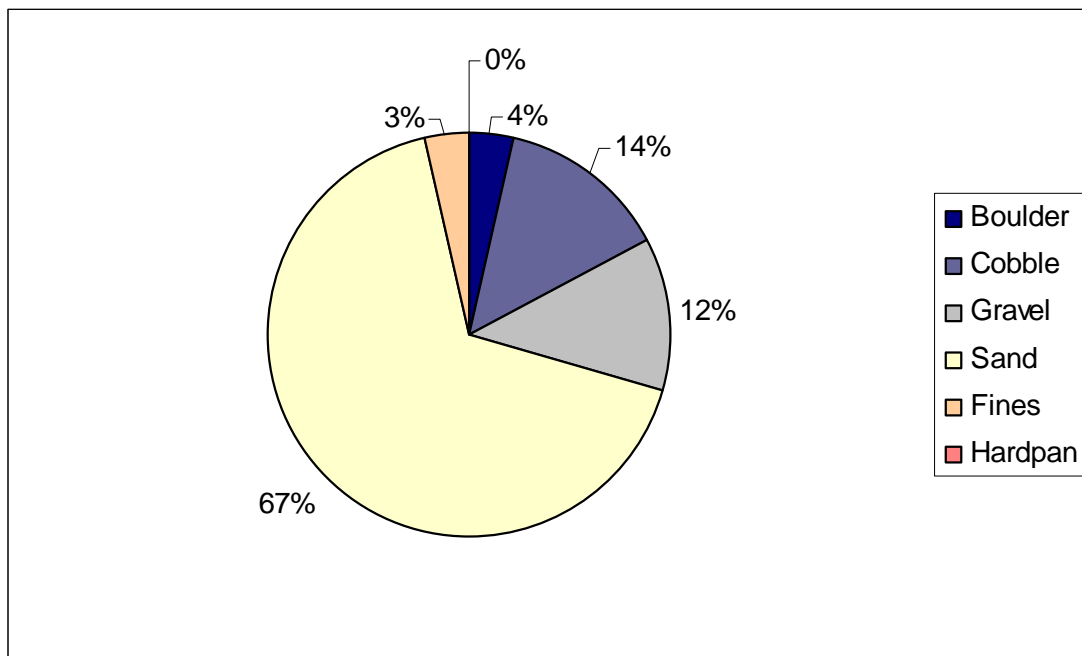


Figure 18. St. Croix River proportional benthic substrate composition.

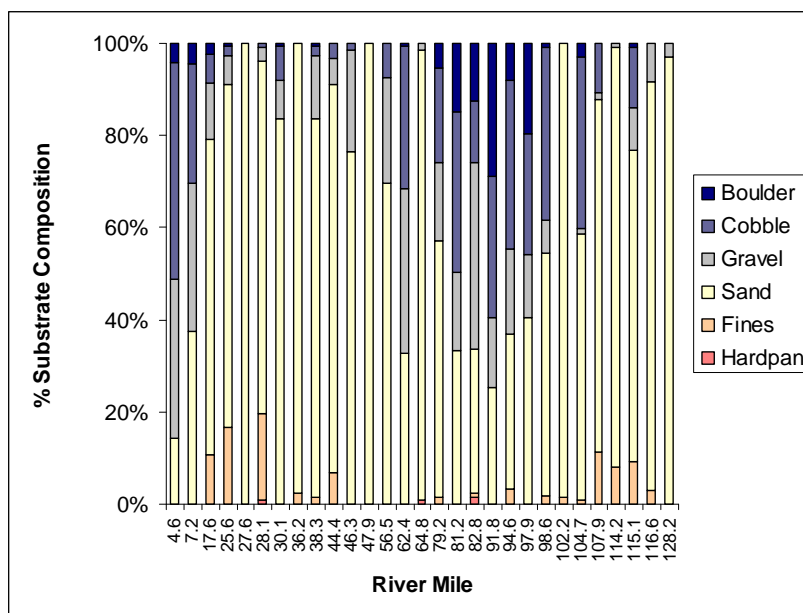


Figure 19. St. Croix River proportional benthic substrate composition at each site. River flow is from right to left.

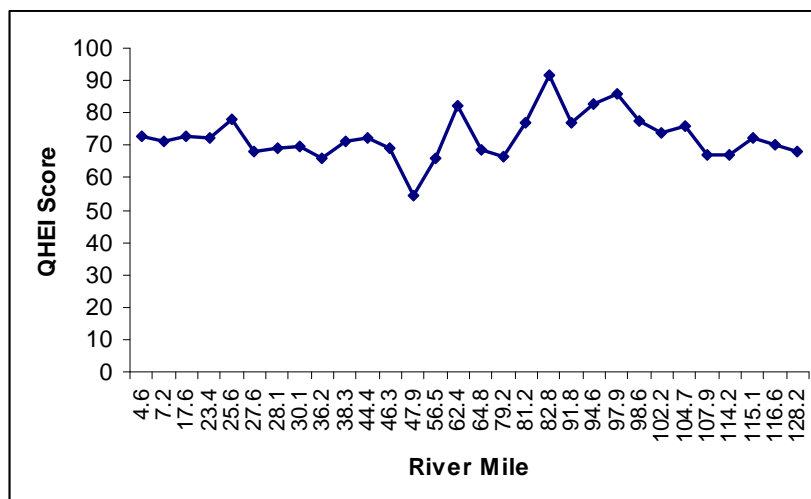


Figure 20. Qualitative habitat evaluation index (QHEI) scores for each river mile sampled on the St. Croix River. River flow is from right to left.

5.2.1.2. T/E and Exotic Species Distribution Summary

As the majority of the St. Croix River forms the boundary between the states of Minnesota and Wisconsin, threatened and endangered species lists from both states apply. All thirty sites sampled fell within the protective jurisdiction of both states. Four species listed in Minnesota and Wisconsin were sampled from the St. Croix River: lake sturgeon (*Acipenser fulvescens*), river redhorse (*Moxostoma carinatum*), crystal darter (*Crystallaria asprella*), and gilt darter (*Percina evides*). *Acipenser fulvescens*, *C. asprella*, and *P. evides* are all listed in Minnesota as species of special concern. Furthermore, *C. asprella* and *P. evides* are also listed in Wisconsin as endangered and threatened, respectively. Wisconsin also lists *M. carinatum* as a state threatened species. Of the four species *M. carinatum* was the most abundant, with 26 individuals captured

from 12 different sites. Four *A. fulvescens* were captured from 3 different sites. Both darter species were rarely captured. Two *C. asprella* each were captured from two sites, and only one *P. evides* was captured from the St. Croix. Overall, 47% of the sites surveyed on the St. Croix River contained state listed species (Appendix 5). No federally listed threatened or endangered species were sampled on the St. Croix River. The only exotic species captured on the St. Croix was the common carp (*Cyprinus carpio*). A total of ninety-eight *C. carpio* were captured from 50% of the St. Croix sites. T/E and exotic species distribution maps are located in Appendix 4.

5.2.1.3. Species Composition; Number of species, Number of individuals, electrofishing times

Fish collections from the thirty sites on the St. Croix River in 2004 produced 65 taxa, including hybrids and exotics, representing 17 families (Appendix 5). Average (SE) numbers of species and individuals collected per site were 18.6 (0.9) and 220.3 (29.7) respectively. Sampling effort was measured in seconds, where electrical current was actively applied to the water. The average electrofishing (EF) time expended per site was 2271.1 seconds. Negotiation of varying degrees of in-stream cover and obstructions led to EF time variation among sites. Likewise, heterogeneous in-stream cover produced variation in fish collections among sites.

Although ‘other’ species comprised 21%, the most abundant individual species were golden redhorse and smallmouth bass, accounting for 15% and 13% of the catch respectively (Figure 21). The ‘other’ species category includes 56 taxa that individually represent < 3% of the total catch. At the family level, Cyprinidae was dominant, comprising 39% of the catch (Figure 22). Additionally, sucker species (Catostomidae) and temperate basses (Centrarchidae) were major components, representing 29% and 22% of the total composition respectively (Figure 22).

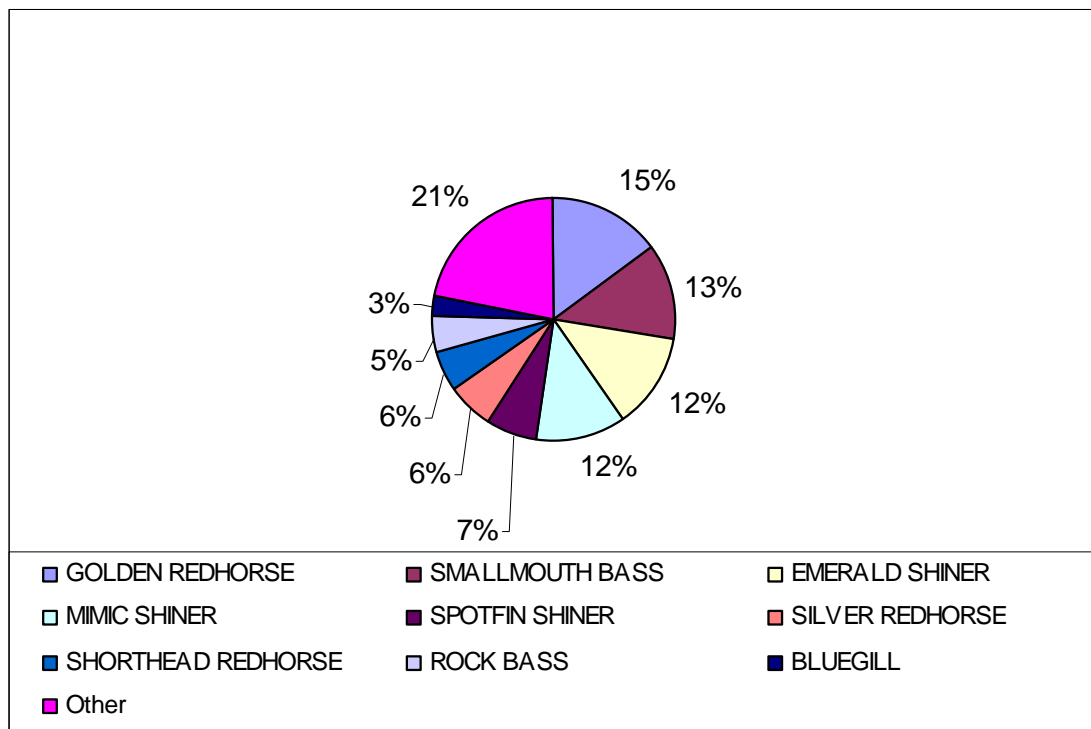


Figure 21. St. Croix River proportional fish species composition.

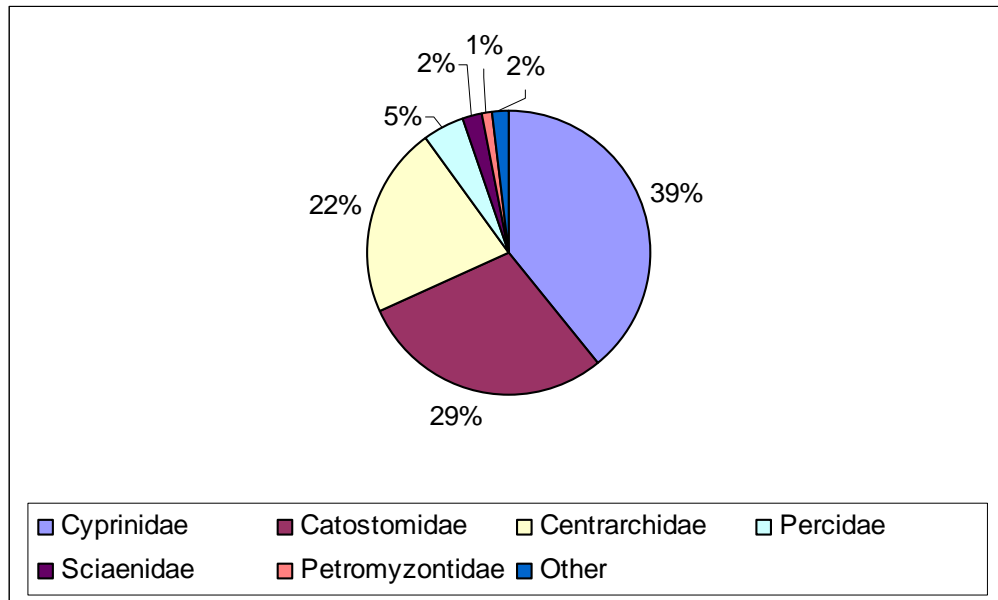


Figure 22. St. Croix River proportional fish family composition.

5.2.1.4. MIwb Scores

As an initial means of estimating biological condition, Modified Index of Well-Being (MIwb) scores were calculated for each of the thirty sites sampled in 2004. The average MIwb score observed was 7.87 and ranged from 6 to 9.62 (Table 6). MIwb scores increased slightly from upstream to downstream (Figure 25). It is reasonable to attribute this slight trend to changes in fish assemblages near the confluence with the upper Mississippi River (Appendix 5).

5.2.1.5. ICD Scores

As an additional means of estimating biological condition, Index of Centers of Density (ICD) scores were calculated for each of the thirty sites sampled in 2004. Scores ranged from 0.16 to 5.89. Increasing ICD scores (higher densities of unique species) occurred in the lower river, and generally tracked well with the MIwb scores (Figure 25). The increase is likely due to the closer proximity to the Mississippi mainstem, which could have accounted for the assemblage changes observed.

5.2.1.6. FAQI Results

The primary means by which we estimated biological condition was to generate a Fish Assemblage Quality Index (FAQI) score for each of the 30 sites on the St. Croix River. On a scale of 0 to 1200, the average FAQI score observed was 782 and ranged from 583 to 899, with more than 50% of the sites scoring above 800 (Figure 23, Table 6). FAQI scores were not significantly correlated with changes in the stressor gradient ($R = 0.41$, Spearman, $p > 0.16$, Figure 24). However, FAQI scores were significantly correlated with both MIwb ($R = 0.85$, Spearman, $p < 0.001$) and ICD scores ($R = 0.62$, Spearman, $p < 0.001$, Figure 25). In comparison to the state IBI scores, the FAQI scores tracked best with those produced by MPCA (Figure 26), as opposed to MDNR, but neither relationships were significant (Spearman $R = 0.08$ and -0.54 ,

respectively both $p > 0.10$). In both cases FAQI scores were approximately 20% lower than the other two indices (Figure 26).

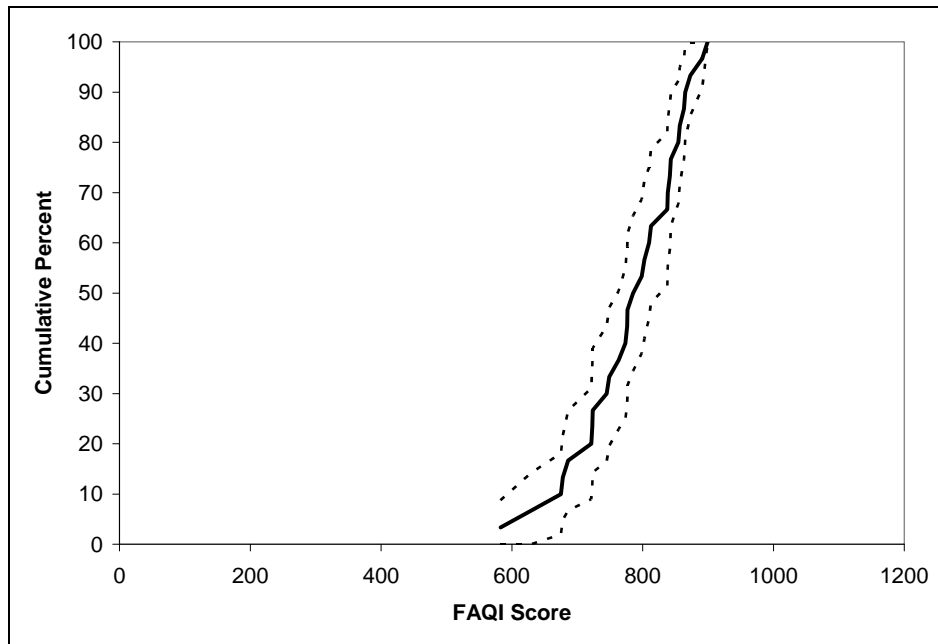


Figure 23. Cumulative distribution frequency (black line) graph of FAQI scores on the St. Croix River (dotted lines = 95% confidence bands).

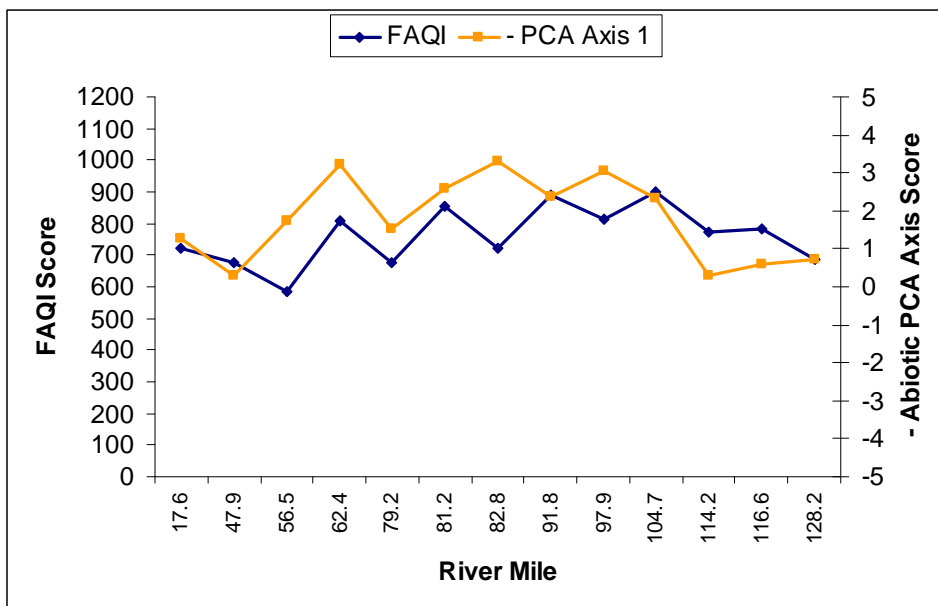


Figure 24. FAQI and the inverse PCA Axis 1 ('+' = good habitat/water quality, '-' = poor habitat/water quality) scores for all St. Croix River sites included in the abiotic PCA. River flow is from right to left.

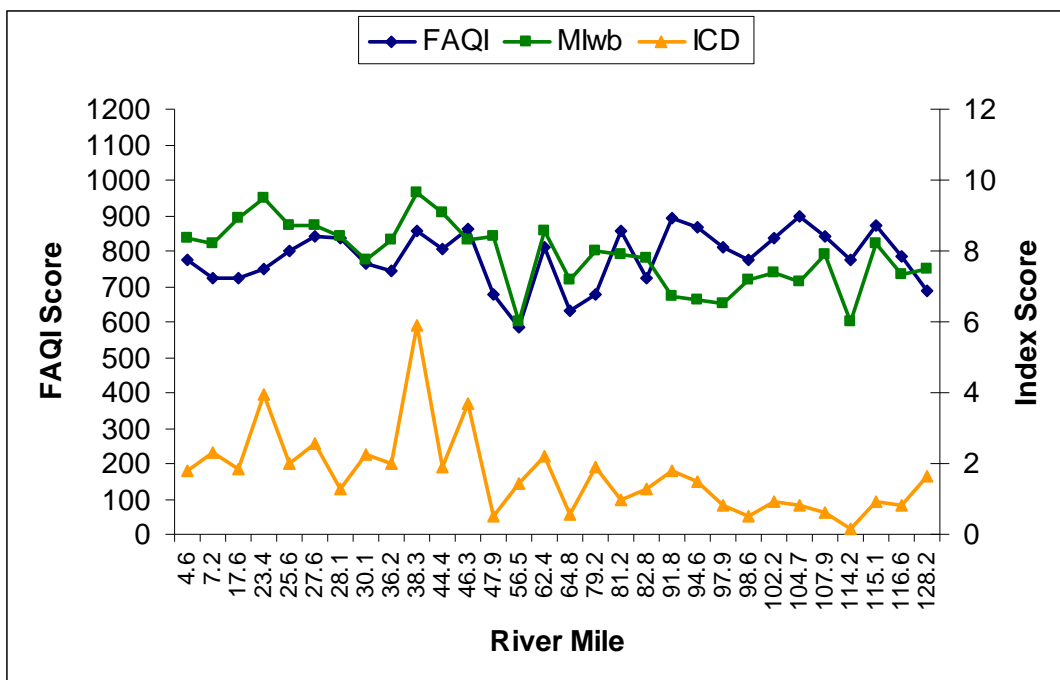


Figure 25. St. Croix River FAQI, MIwb, and ICD scores. River flow is from right to left.

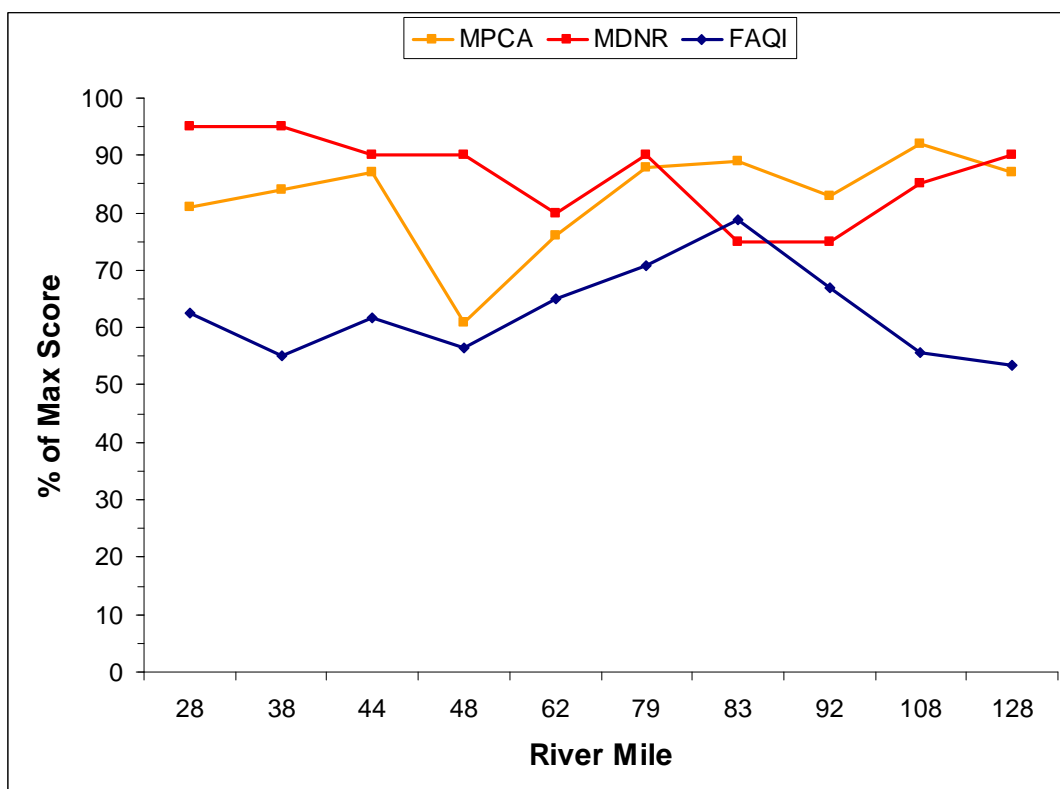


Figure 26. Multimetric index scores (labeled) for the St. Croix produced by Minnesota Pollution Control (MPCA), Minnesota Department of Natural Resources (MDNR), and ORSANCO (FAQI). River flow is from right to left.

5.2.2. WABASH RIVER

Between July and October 2004, electrofishing and habitat data were collected at 30 sites between river miles 7 and 380. Of the 30 completed sites, 21 were sampled at night and 9 were sampled during the day. During the 2005 index period, water chemistry and nutrient data were collected by USEPA at 18 overlapping sites.

5.2.2.1. Habitat / Water Quality Summary

Intensive physical habitat survey data taken from each of the thirty electrofishing sites revealed benthic substrate composition to be dominated by sand (65%). Coarser substrates combined to comprise 23% of the substrate (Figure 27), and were found sporadically throughout the river (Figure 28). Though, fines comprised only a small portion of the substrate in Wabash sites overall (11%), there were some sites with large concentrations (> 60%) near the mouth of the river (Figure 28). Hardpan was found only at a very small portion of the sites (Figure 27). Submerged aquatic vegetation was present at 7% of the sites. Overhanging vegetation and in-stream woody cover were present at 83% and 97% of the sites, respectively (Appendix 5). QHEI, water quality parameters, and nutrient data were collected when possible. Data gaps are attributable to equipment/ calibration failure. The average (SE) QHEI score for the Wabash River was 59.6 (0.99). Scores varied slightly across sites (Figure 29). Average pH was 9.59 (0.40). Temperature averaged 16.51°C (0.80), and dissolved oxygen content averaged 11.42 mg/L (0.34). The river was fairly turbid during sampling events, as conductivity was moderate to high with an average value of 607.71 µs/cm (9.87), and secchi depths averaged 19.37 inches (1.84) (Appendix 5).

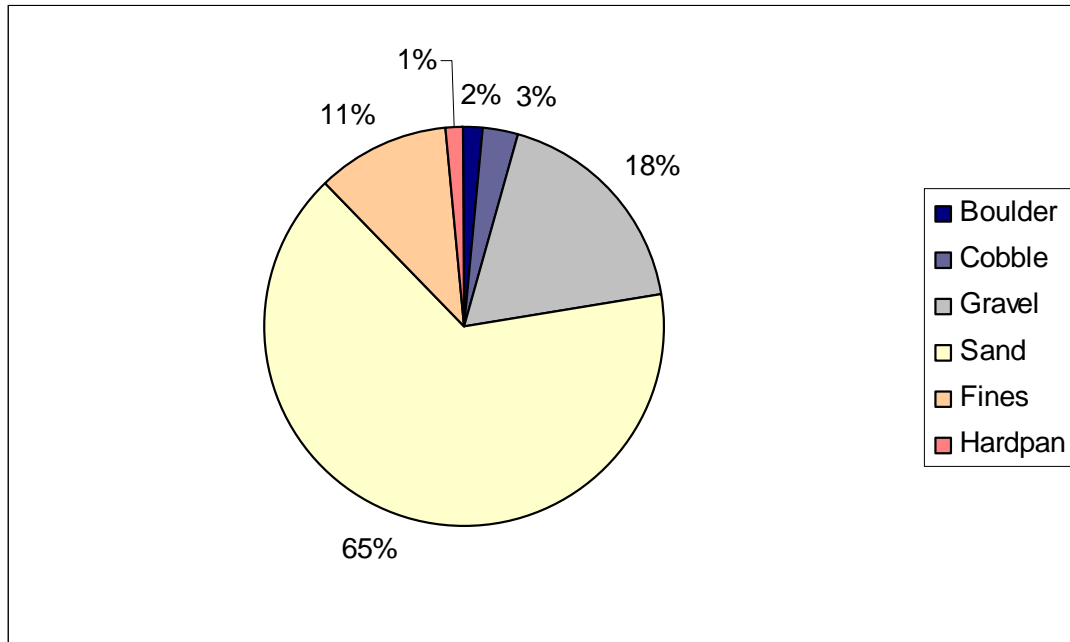


Figure 27. Wabash River proportional benthic substrate composition.

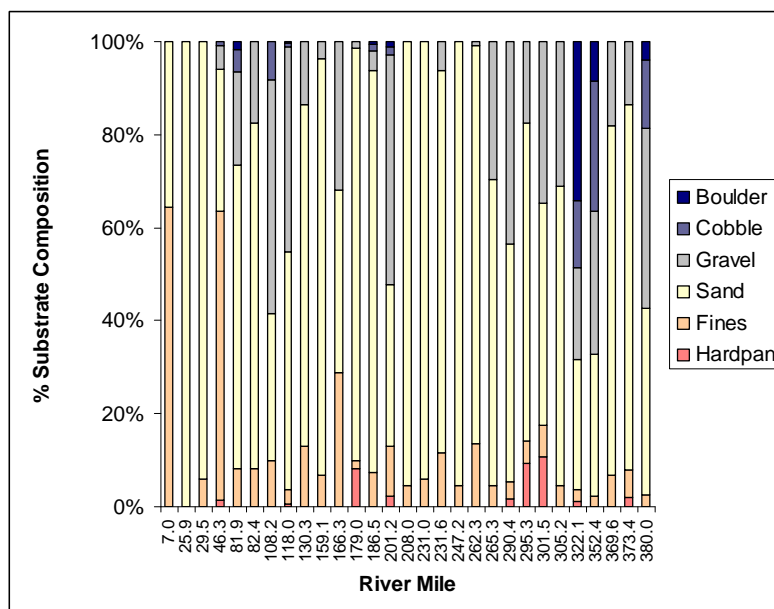


Figure 28. Wabash River proportional benthic substrate composition at each site. River flow is from right to left.

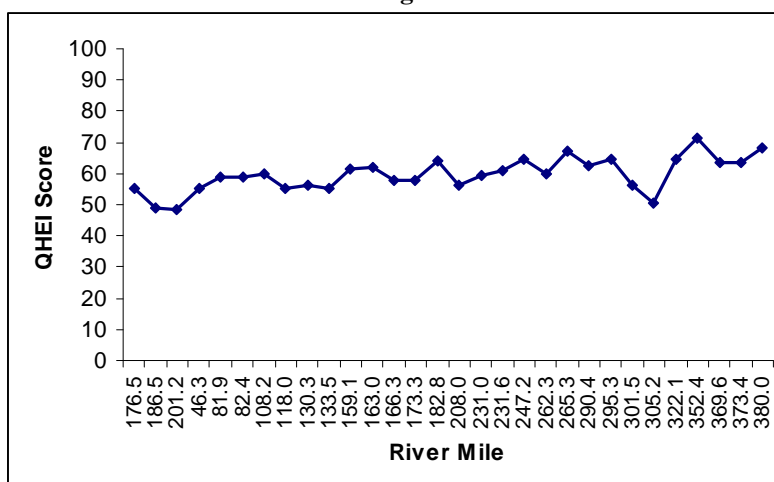


Figure 29. Qualitative habitat evaluation index (QHEI) scores for each river mile sampled on the Wabash River. River flow is from right to left.

5.2.2.2. T/E and Exotic Species Distribution Summary

The lower 194 miles of the Wabash River forms the boundary between the states of Illinois and Indiana. Within this section of the river threatened and endangered species lists from both states apply. Fourteen of the thirty sites sampled fell in the lower 187 river miles. Data from these sites were subject to the protective jurisdiction of both states. Two species listed in Illinois were sampled from the Wabash River: the endangered bigeye chub (*Hybopsis amblops*) and the threatened gravel chub (*Erimystax x-punctatus*). Thirteen *H. amblops* and 4 *E. x-punctatus* were sampled from 5 and 2 sites, respectively. These two state-listed species were sampled from 20% of the sites surveyed on the Wabash River (Appendix 5). No federally listed threatened or endangered species were sampled on the Wabash River. Exotic species were collected at 90% of the sites on the Wabash River. These included 2 bighead carp (*Hypophthalmichthys nobilis*) from 2 sites, 1 common carp / goldfish hybrid from 1 site, a total of 274 common carp (*Cyprinus*

carpio) from 26 sites, 1 goldfish (*Carassius auratus*) from 1 site, 3 grass carp (*Ctenopharyngodon idella*) from 3 sites, 10 white bass / striped bass hybrids from 7 sites, and 6 silver carp (*Hypophthalmichthys molitrix*) at one site. Exotic and T/E species distribution maps are located in Appendix 4.

5.2.2.3. Species Composition / Metrics; Number of species, Number of individuals, electrofishing times

Fish collections from the thirty sites on the Wabash River in 2004 produced 73 taxa, including hybrids and exotics, representing 13 families (Appendix 5). Average (SE) numbers of species and individuals collected per site were 16.7 (1.0) and 125.0 (15.3), respectively. Sampling effort was measured in seconds, where electrical current was actively applied to the water. The average electrofishing (EF) time expended per site was 2002.4 seconds. Negotiation of varying degrees of in-stream cover and obstructions led to EF time variation among sites. Likewise, heterogeneous in-stream cover produced variation in fish collections between sites.

Although ‘other’ species comprised 21%, the most abundant individual species were freshwater drum, emerald shiner and gizzard shad, accounting for 22%, 13% and 13% of the catch respectively (Figure 30). The ‘other’ species category includes 64 taxa that individually represent < 2% of the total catch. At the family level, Cyprinidae was dominant, comprising 35% of the catch (Figure 38). Additionally, Sciaenidae were major components, representing 21% of the total composition (Figure 31).

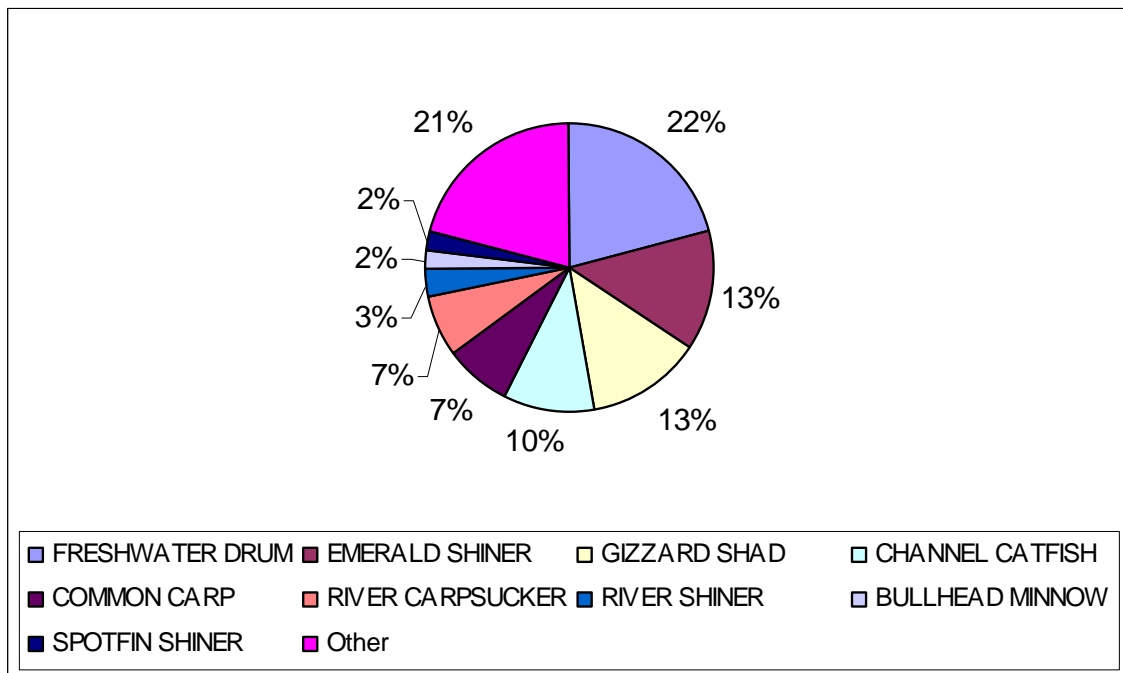


Figure 30. Wabash River proportional fish species composition.

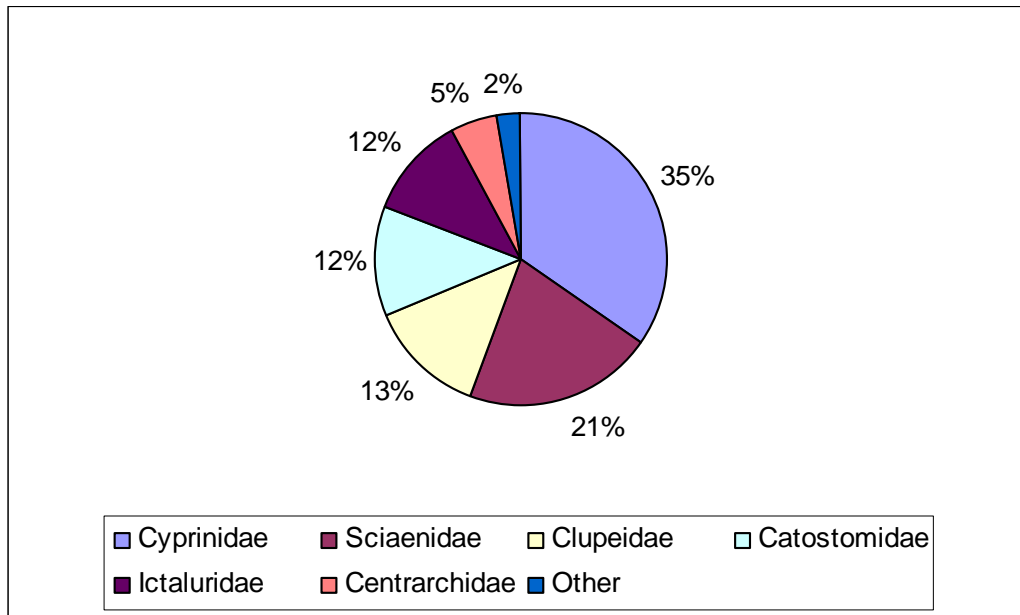


Figure 31. Wabash River proportional fish family composition.

5.2.2.4. MIwb Scores

Modified Index of Well-Being (MIwb) scores were calculated for each of the thirty sites sampled in 2004. The average MIwb score observed was 7.13 and ranged widely from 2.9 to 8.8 (Table 6). High quality sites were of sporadic distribution. No specific trends existed with respect to river mile, QHEI or substrate composition.

5.2.2.5. ICD Scores

Index of Centers of Density (ICD) scores were calculated for each of the thirty sites sampled in 2004. Scores ranged from 0.25 to 7.98. Increasing ICD scores (higher densities of unique species) occur primarily within the upper reaches (Figure 34). These peaks are likely due to increased capture rates of unique species sampled over coarse substrates (Figure 28).

5.2.2.6. FAQI Results

Fish Assemblage Quality Index (FAQI) scores were generated for each of the 30 sites on the Wabash River. On a scale of 0 to 1200, the average FAQI score observed was 381.5 and ranged from 199 to 659 with more than 70% of the sites scoring less than 400. FAQI scores on the Wabash were significantly correlated with the observed stressor gradient ($R = 0.65$, Spearman, $p < 0.02$, Figure 33). FAQI scores were also correlated with MIwb ($R = 0.85$, Spearman, $p < 0.001$) and ICD scores ($R = 0.55$, Spearman, $p < 0.002$, Figure 34). FAQI scores were not correlated with ($R = -0.22$, Spearman, $p > 0.60$), and were on average, 16% lower than the IDEM IBI scores (Figure 35).

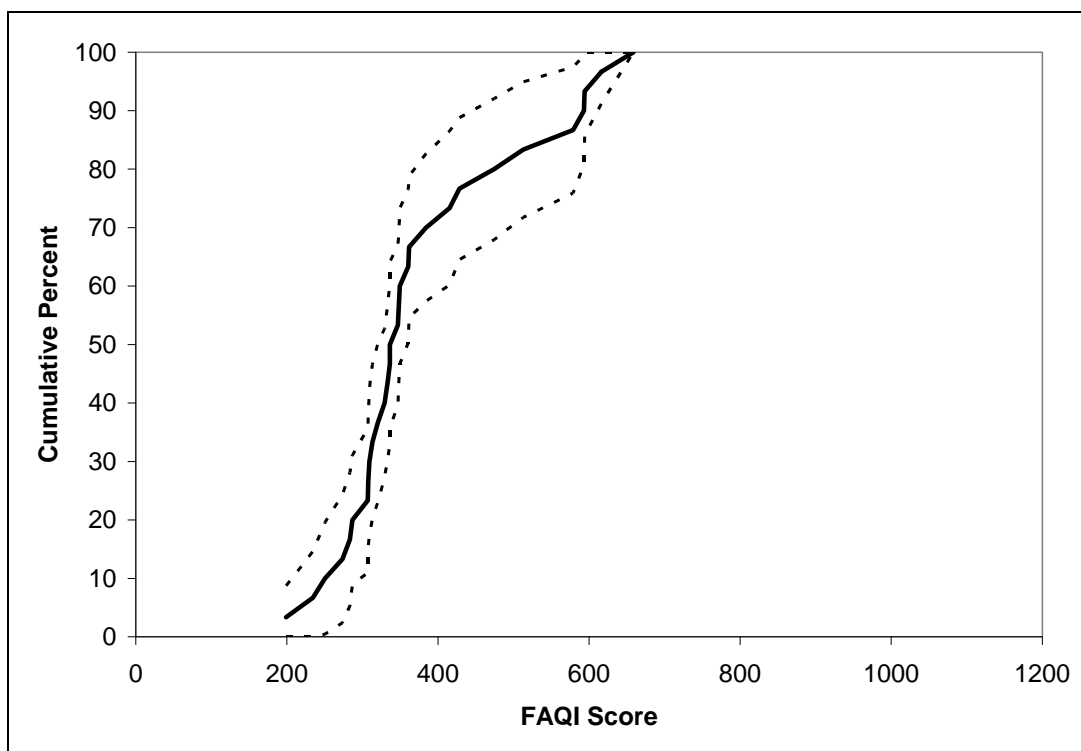


Figure 32. Cumulative distribution function (black line) graph of FAQI scores on the Wabash River (dotted lines = 95% confidence bands).

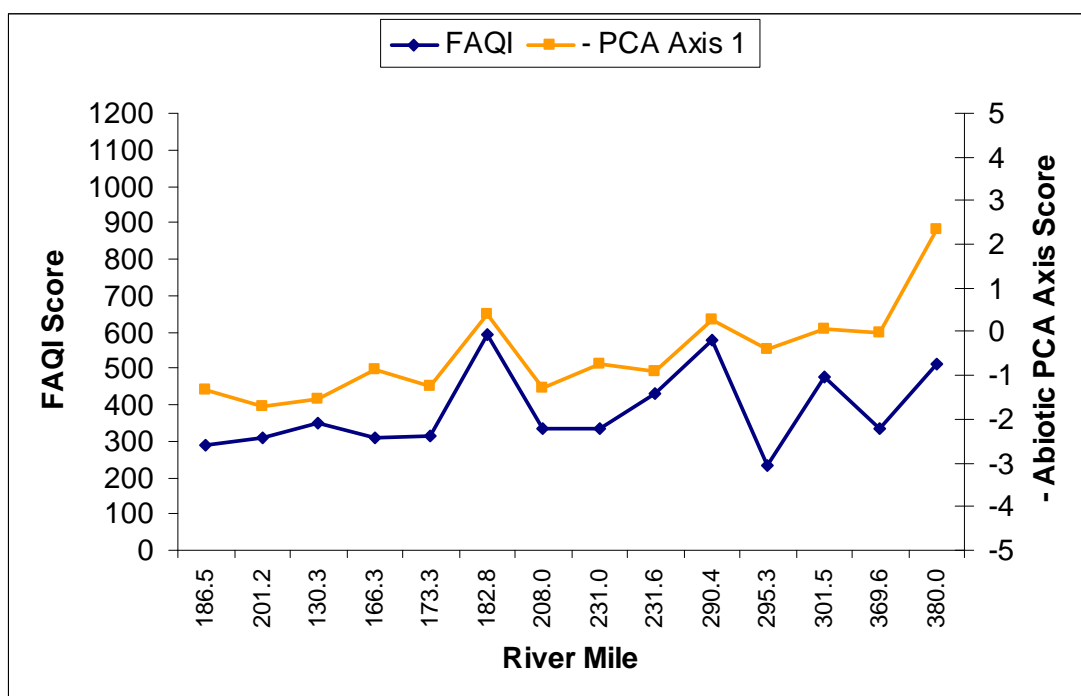


Figure 33. FAQI and the inverse PCA Axis 1 ('+' = good habitat/water quality '-' = poor habitat/water quality) scores for all Wabash River sites included in the abiotic PCA. River flow is from right to left.

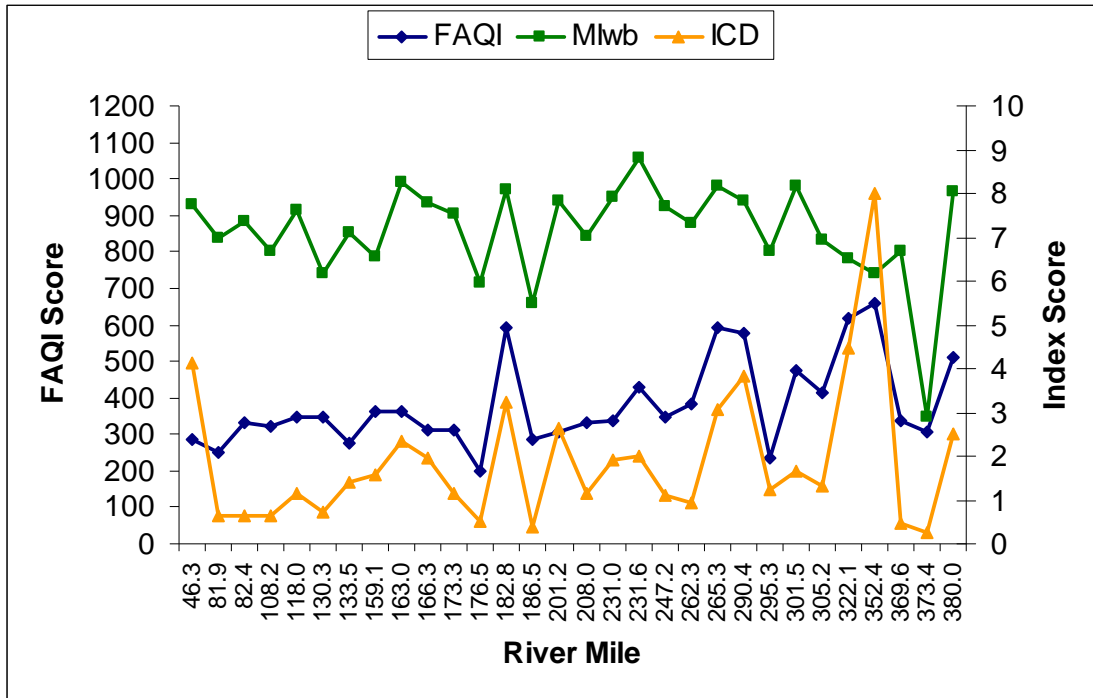


Figure 34. FAQI, MIwb, and ICD scores for all sites sampled on the Wabash River. River flow is from right to left.

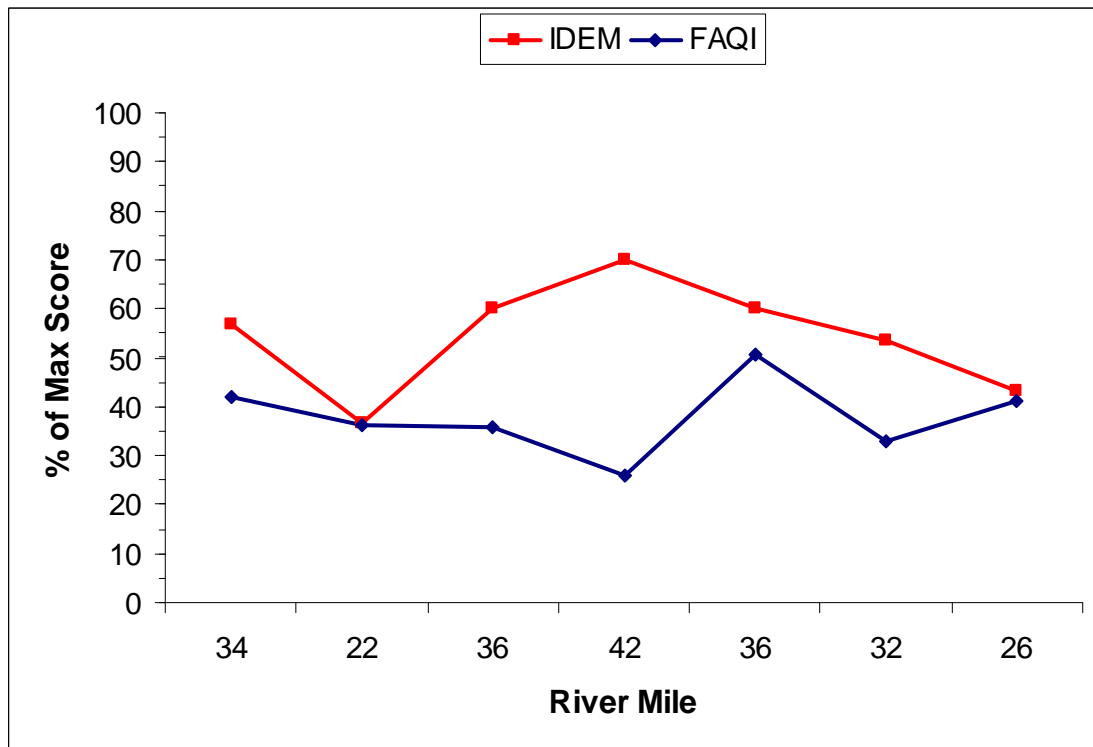


Figure 35. Multimetric index scores (labeled) for the Wabash River produced by Indiana Department of Environmental Management (IDEM) and ORSANCO (FAQI). River flow is from right to left.

5.2.3. WISCONSIN RIVER

Between July and September 2005, electrofishing was conducted at 29 sites between river miles 3 and 307. The remaining site was not sampled due to navigational error. Habitat data were collected from only 28 of the 29 completed sites due to a miscommunication. Of the 28 sites for which electrofishing and habitat data were taken, 12 were sampled at night and 16 were sampled during the day. During the 2004 index period, water chemistry and nutrient data were collected by USEPA at 18 overlapping sites.

5.2.3.1. Habitat / Water Quality Summary

Intensive physical habitat survey data taken from each of the thirty electrofishing sites revealed benthic substrate composition to be dominated by sand. Coarser substrates combined to comprise 25% of the substrate (Figure 36), increasing in prevalence, along with fine substrates, towards the source of the river (Figure 37). Fines and hardpan comprised 3% and 1% respectively (Figure 36). Submerged aquatic vegetation was present at 21% of the sites. Overhanging vegetation and in-stream woody cover were present at 100% and 96% of the sites, respectively (Appendix 5). QHEI, water quality parameters, and nutrient data were collected when possible. Data gaps are attributable to equipment/ calibration failure. The average (SE) QHEI score for the Wisconsin River was 58.8 (1.99). Scores regularly fluctuated by as much as 20 points between neighboring sites (Figure 38). Average pH was 8.53 (0.15). Temperature averaged 24.55°C (0.32), and dissolved oxygen content averaged 9.0 mg/L (0.35). Conductivity was relatively low with an average value of 214.46µs/cm (11.34). Secchi depths averaged 16.14 inches (1.35) (Appendix 5).

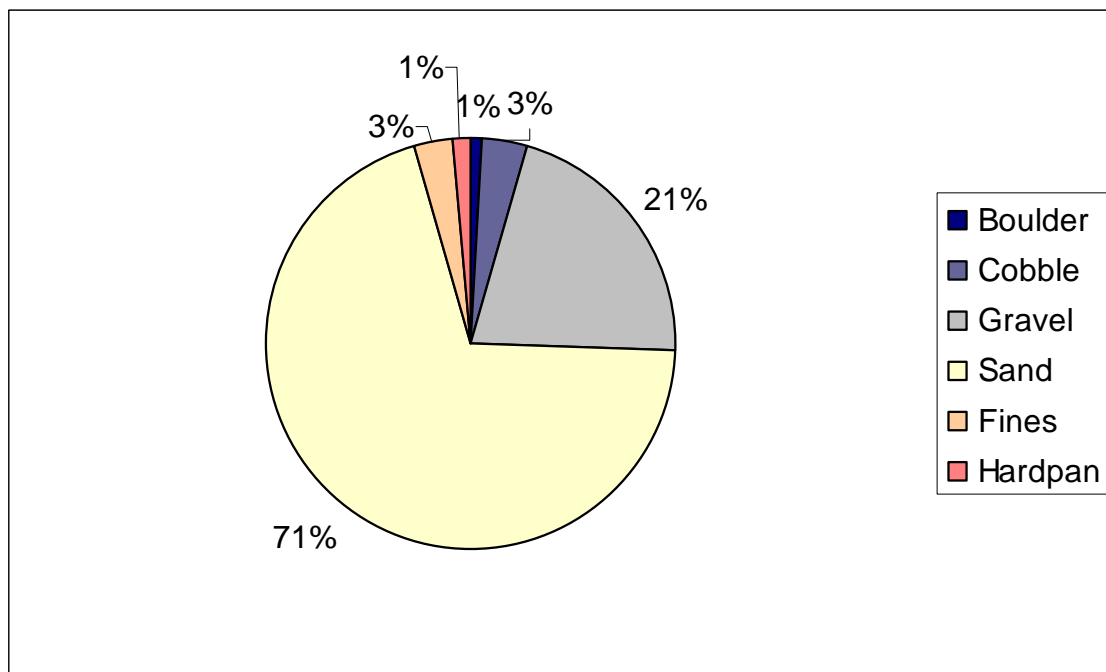


Figure 36. Wisconsin River proportional benthic substrate composition.

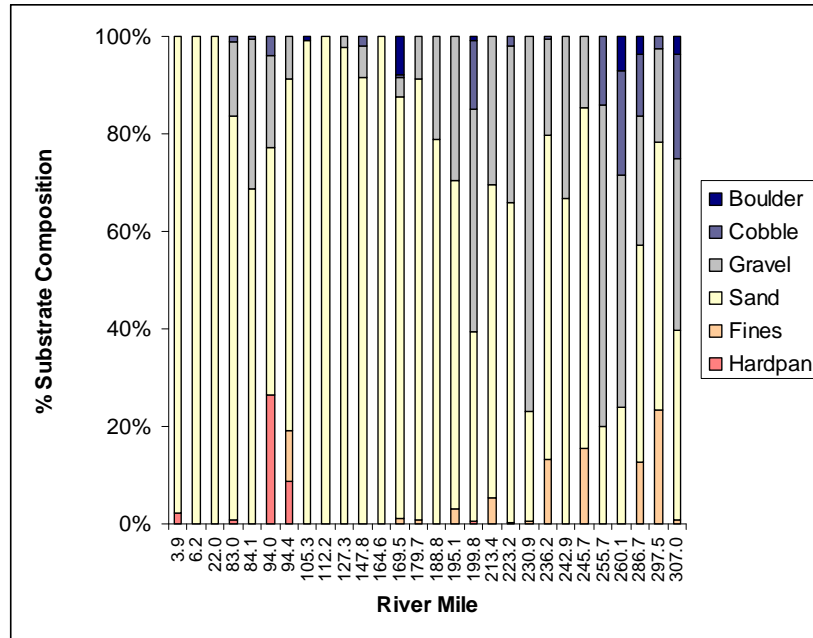


Figure 37. Wisconsin River proportional benthic substrate composition at each site. River flow is from right to left.

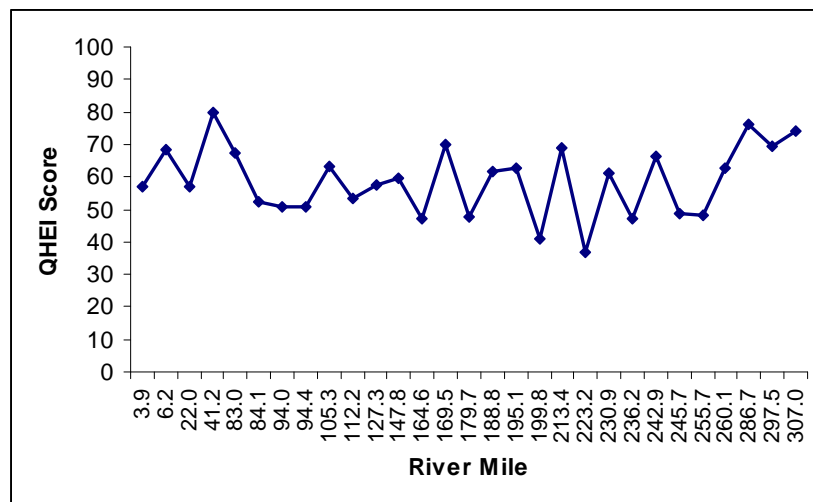


Figure 38. Qualitative habitat evaluation index (QHEI) scores for each river mile sampled on the Wisconsin River. River flow is from right to left.

5.2.3.2. T/E and Exotic Species Distribution Summary

Three species listed in Wisconsin were sampled; the threatened shoal chub (*Macrhybopsis hyostoma*), blue sucker (*Cycleptus elongatus*), and black buffalo (*Ictibus niger*). The most abundant of these species was *C. elongatus* which were captured from 3 different sites. Overall, 21% of the sites surveyed on the Wisconsin River contained state listed species (Appendix 5). No federally listed threatened or endangered species were sampled on the Wisconsin River. One exotic species, common carp (*Cyprinus carpio*), was captured at 83% of the sites on the Wisconsin River. Exotic and T/E species distribution maps are located in Appendix 4.

5.2.3.3. Species Composition / Metrics; Number of species, Number of individuals, electrofishing times

Fish collections from the twenty-nine sites on the Wisconsin River in 2005 produced 72 taxa, including exotics, representing 18 families (Appendix 5). Average (SE) numbers of species and individuals collected per site were 14.5 (1.2) and 245.1 (46.2), respectively. Sampling effort was measured in seconds, where electrical current was actively applied to the water. The average electrofishing (EF) time expended per site was 2306.5 seconds. Negotiation of varying degrees of in-stream cover and obstructions led to EF time variation within sites.

Although ‘other’ species comprised 42%, the most abundant individual species were emerald shiner and bluegill sunfish, accounting for 10% and 9% of the catch, respectively (Figure 39). The ‘other’ species category includes 65 taxa that individually represent < 4% of the total catch. At the family level, Cyprinidae was dominant, comprising 25% of the catch (Figure 40). Additionally, temperate basses (Centrarchidae) were a major component, representing 22% of the total composition (Figure 40).

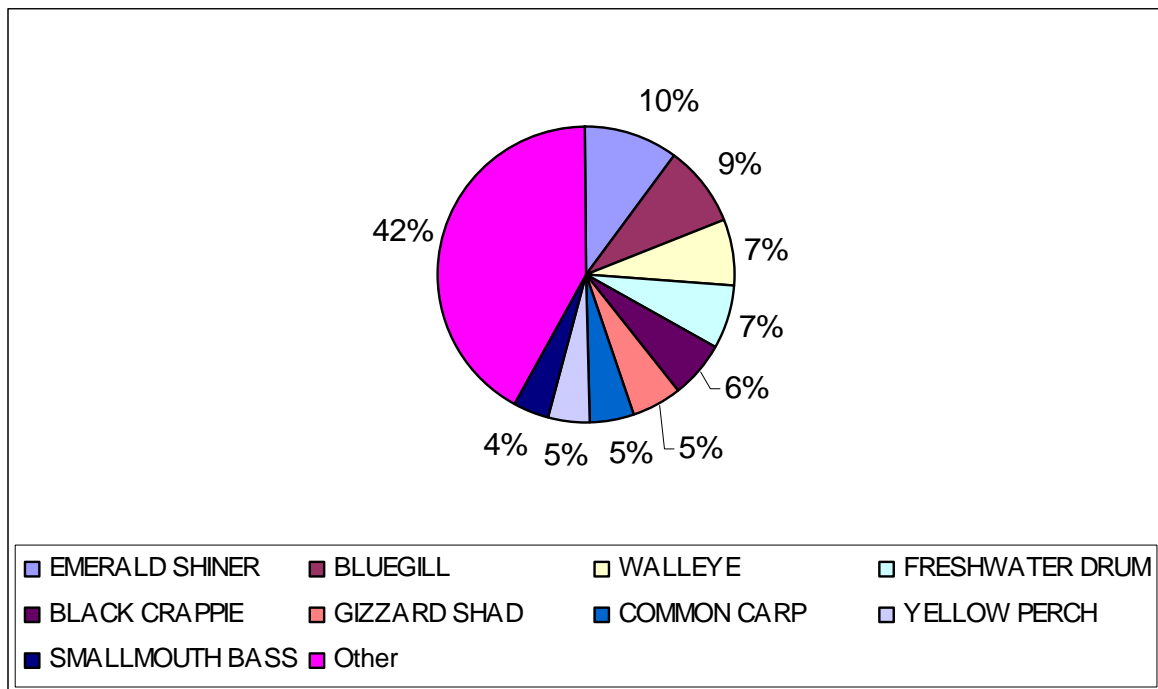


Figure 39. Wisconsin River proportional fish species composition.

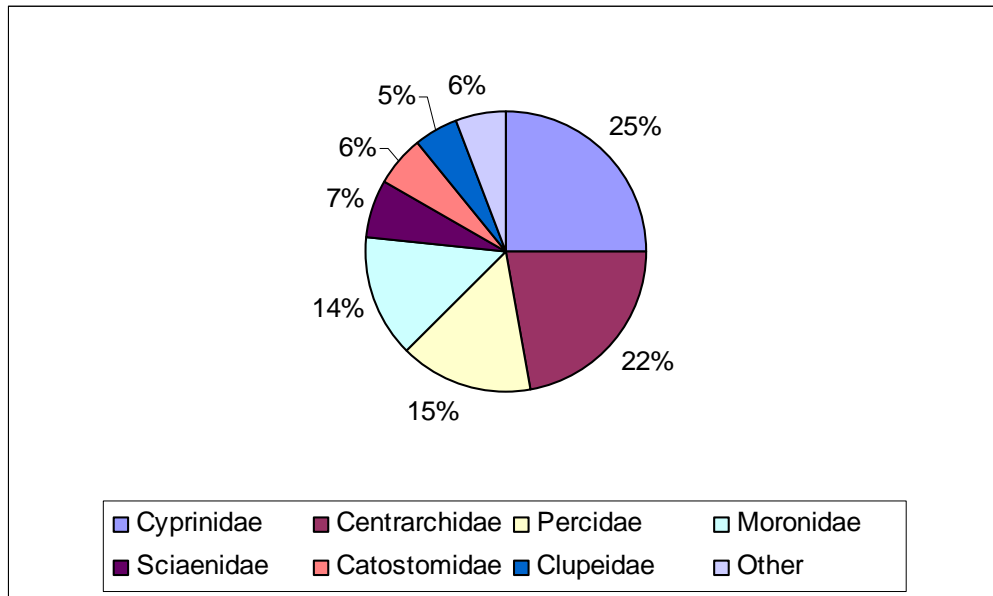


Figure 40. Wisconsin River proportional fish family composition.

5.2.3.4. MIwb Scores

Modified Index of Well-Being (MIwb) scores were calculated for each of the twenty-nine sites sampled in 2005. The average MIwb score observed was 6.91 and ranged from 3.26 to 9.97 (Table 6). MIwb scores exhibited a slight upstream to downstream trend with respect to river mile (Figure 43). This trend was attributed to changes in fish assemblages and higher diversity (Appendix 5) in the free-flowing portions of the river as it flows towards its confluence with the upper Mississippi River.

5.2.3.5. ICD Scores

Index of Centers of Density (ICD) scores were calculated for each of the twenty-nine sites sampled in 2005. Scores ranged from 0.05 to 8.4. Increasing ICD scores (higher densities of unique species) occurred primarily within the lower to middle reaches (Figure 43).

5.2.3.6. FAQI Results

Fish Assemblage Quality Index (FAQI) scores were generated for each of the 29 sites on the Wisconsin River. On a scale of 0 to 1200, the average FAQI score observed was 582 and ranged from 360 to 720, with 40% of the sites scoring above 600 (Figure 38). FAQI scores were not correlated with the stressor gradient observed on the Wisconsin River ($R = -0.10$, Spearman, $p > 0.59$, Figure 42). FAQI scores were significantly correlated with ICD score ($R = 0.62$, Spearman, $p < 0.001$, Figure 43), but were not correlated with MIwb scores ($R = 0.14$, Spearman, $p > 0.45$, Figure 43). Only having four common sites, FAQI scores were not correlated with the IBI scores provided by WDNR ($R = 0.63$, Spearman, $p > 0.36$, and were nearly 44% lower (Figure 44).

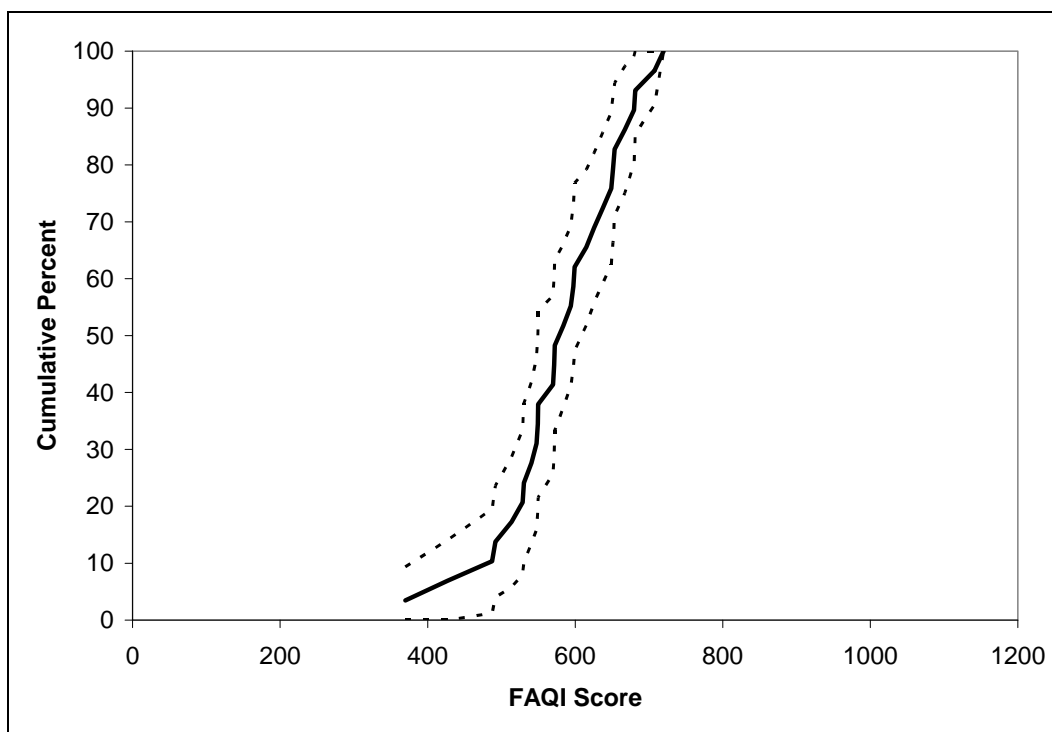


Figure 41. Cumulative distribution function (black line) graph of FAQI scores on the Wisconsin River (dotted lines = 95% confidence bands).

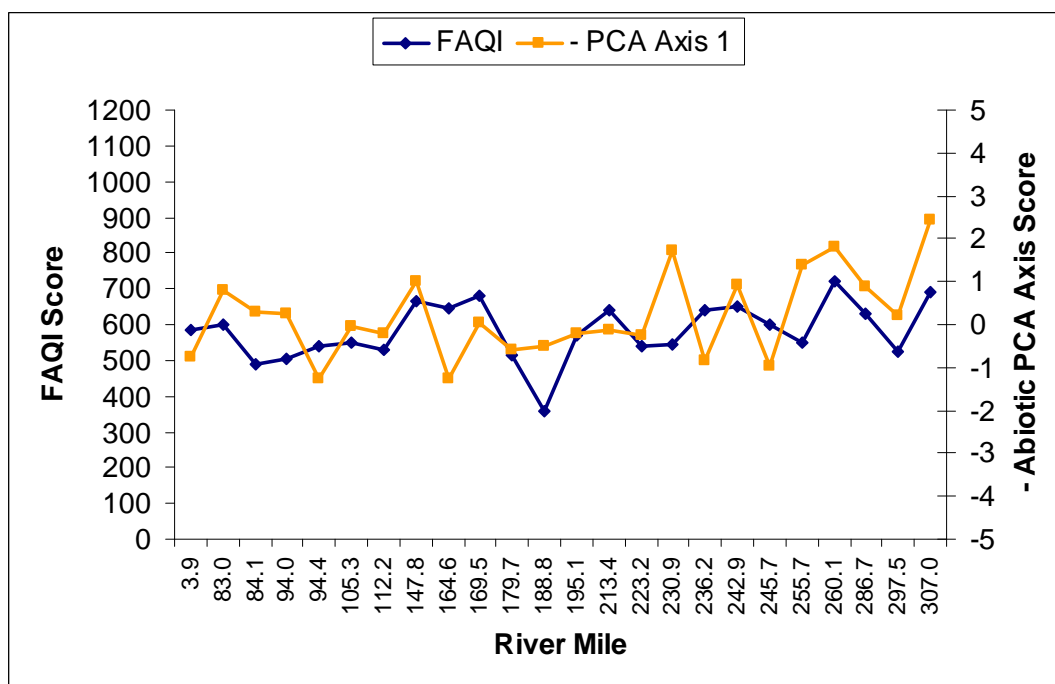


Figure 42. FAQI and the inverse PCA Axis 1 ('+' = good habitat/water quality, '-' = poor habitat/water quality) scores for all Wisconsin River sites included in the abiotic PCA. River flow is from right to left.

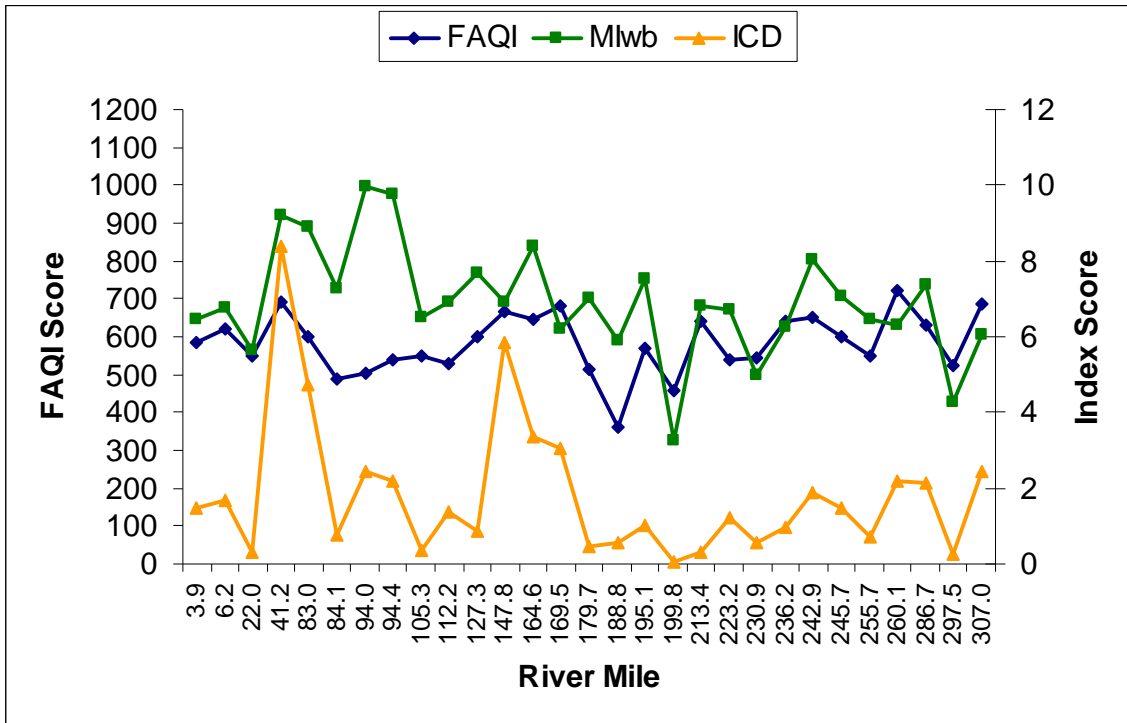


Figure 43. Wisconsin River FAQI, MIwb, and ICD scores. River flow is from right to left.

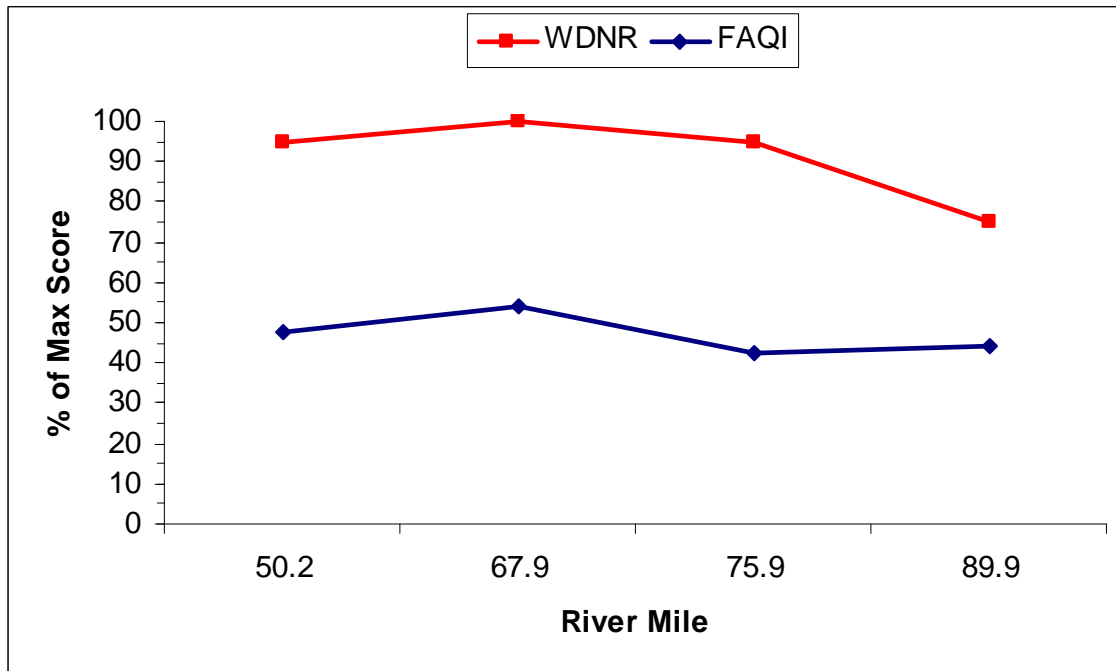


Figure 44. Multimetric index scores (labeled) for the Wisconsin River produced by Wisconsin Department of Natural Resources (WDNR) and ORSANCO (FAQI). River flow is from right to left.

5.2.4. SCIOTO RIVER

Between July and October 2005, electrofishing data was collected from 30 sites between river miles 1 and 150. Corresponding habitat data was only recorded at 21 of those sites due to a miscommunication between the two crews coordinating the collection of fish and habitat data. Of the 30 sites, three were sampled at night and 27 were sampled during the day. During the same index period, water chemistry and nutrient data were collected by USEPA at 18 overlapping sites.

5.2.4.1. Habitat / Water Quality Summary

Intensive physical habitat survey data taken from 21 of the thirty electrofishing sites revealed benthic substrate composition to be dominated by sand and gravel (76%), (Figure 45) a pattern that was observed along the entire length of the Scioto River, with few exceptions (Figure 46). Coarser substrates combined to comprise 10% of the substrate (Figure 45). Fines and hardpan comprised 8% and 6% respectively (Figure 45). Higher percentages of hardpan exist in the upper reaches of the river (Figure 46). Submerged aquatic vegetation was present at 5% of the sites. Overhanging vegetation and in-stream woody cover were present at 91% and 95% of the sites, respectively (Appendix 5). QHEI, water quality parameters, and nutrient data were collected when possible. Data gaps are attributable to equipment/ calibration failure. The average (SE) QHEI score for the Scioto River was 63.5 (2.08). Scores were lowest near the source and mouth, peaking in the middle to upper reaches of the river, declining again in the uppermost sites Figure 47). Average pH was 8.58 (0.15). Temperature averaged 22.17°C (1.25), and dissolved oxygen content averaged 9.8 mg/L (0.58). Conductivity was moderate to high, with an average value of 646.57µs/cm (15.86). Secchi depths averaged 20.76 inches (1.48) (Appendix 5).

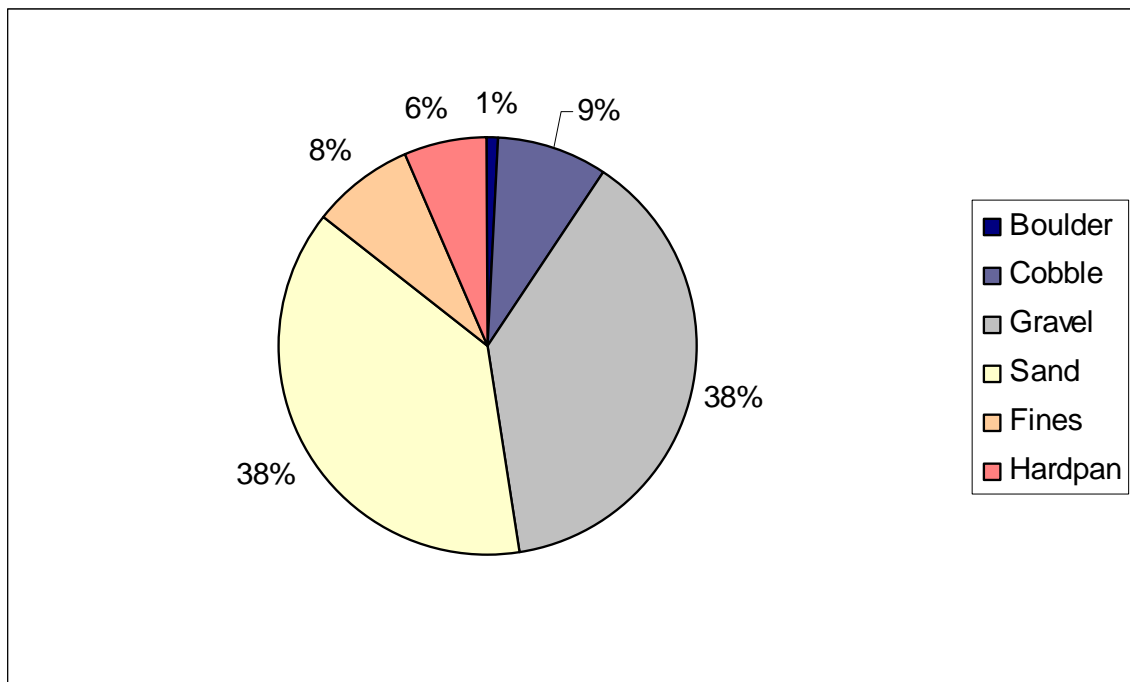


Figure 45. Scioto River proportional benthic substrate composition.

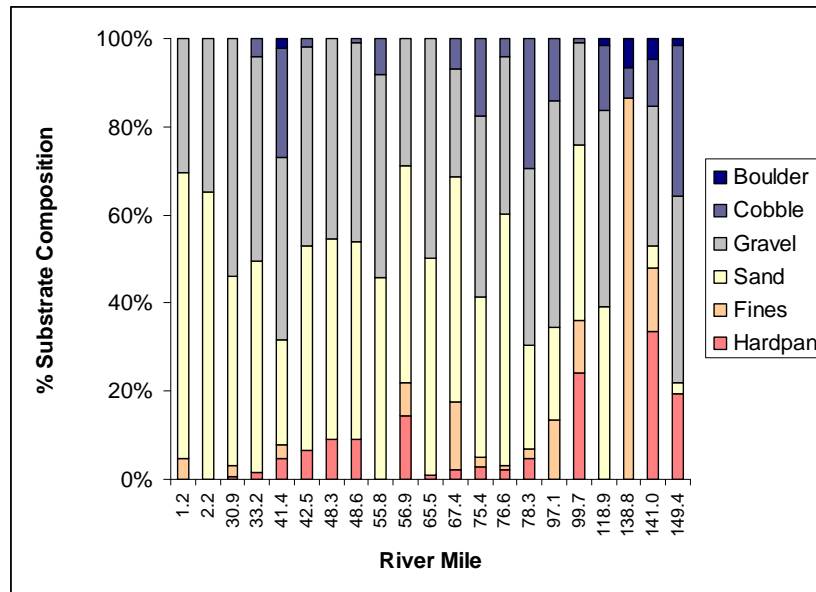


Figure 46. Scioto River proportional benthic substrate composition at each site. River flow is from right to left.

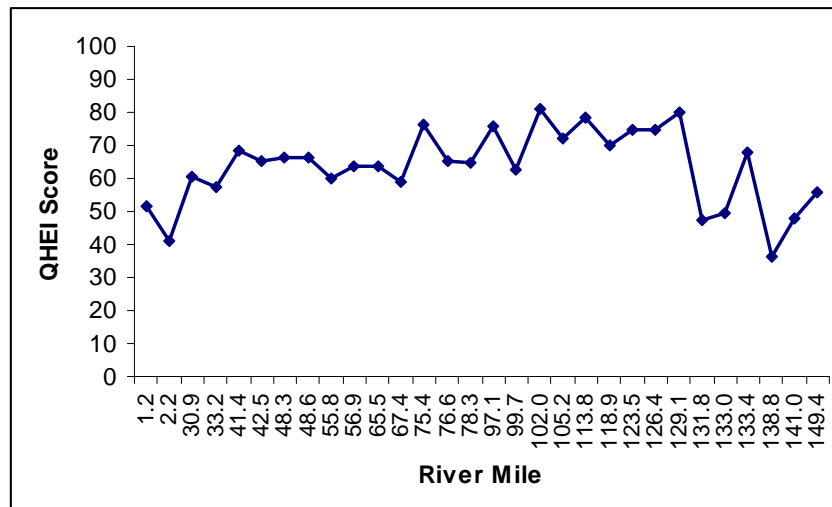


Figure 47. Qualitative habitat evaluation index (QHEI) scores for each river mile sampled on the Scioto River. River flow is from right to left.

5.2.4.2. T/E and Exotic Species Distribution Summary

The entirety of the Scioto River lies within the state of Ohio. All thirty sites sampled along its length were subject to the state's threatened and endangered species list. Five species listed in Ohio were sampled from the Scioto River: the endangered shoal chub (*Macrhybopsis hyostoma*), the threatened paddlefish (*Polyodon spathula*), tippecanoe darter (*Etheostoma tippecanoe*), and bluebreast darter (*Etheostoma camurum*), and the river redhorse (*Moxostoma carinatum*), which is a species of special concern. The most abundant of these species was *M. carinatum*, of which 12 individuals were captured from 3 different sites. *Etheostoma tippecanoe* were also captured at 3 different sites, but only one individual was captured within each zone. Three *E. camurum* were captured from 2 different sites. And only one individual was captured of both *M. hyostoma* and *P. spathula*. Overall, 23% of the sites surveyed on the Scioto River contained state listed species

(Appendix 5). No federally listed threatened or endangered species were sampled on the Scioto River. Exotic species were collected at 73% of the sites on the Scioto River. These included 207 common carp (*Cyprinus carpio*) from 22 sites, 2 grass carp (*Ctenopharyngodon idella*) from 2 sites, and 32 redear sunfish (*Lepomis microlophus*) from 2 sites. T/E and exotic species distribution maps are located in Appendix 4.

5.2.4.3. Species Composition / Metrics; Number of species, Number of individuals, electrofishing times

Fish collections from the thirty sites on the Scioto River in 2005 produced 77 taxa, including hybrids and exotics, representing 12 families (Appendix 5). Average (SE) numbers of species and individuals collected per site were 21.9 (1.8) and 461.6 (89.1), respectively. Sampling effort was measured in seconds, where electrical current was actively applied to the water. The average electrofishing (EF) time expended per site was 2218.4 seconds. Negotiation of varying degrees of in-stream cover and obstructions led to EF time variation within sites.

The most abundant individual species were gizzard shad, and emerald shiner, accounting for 36% and 20% of the catch, respectively (Figure 48). The 'other' species category includes 68 taxa that individually represent < 2% of the total catch. At the family level, Clupeidae was dominant, comprising 34% of the catch (Figure 49). Additionally, drum (Sciaenidae) and temperate basses (Centrarchidae) were major components, representing 31% and 19% of the total composition respectively (Figure 49).

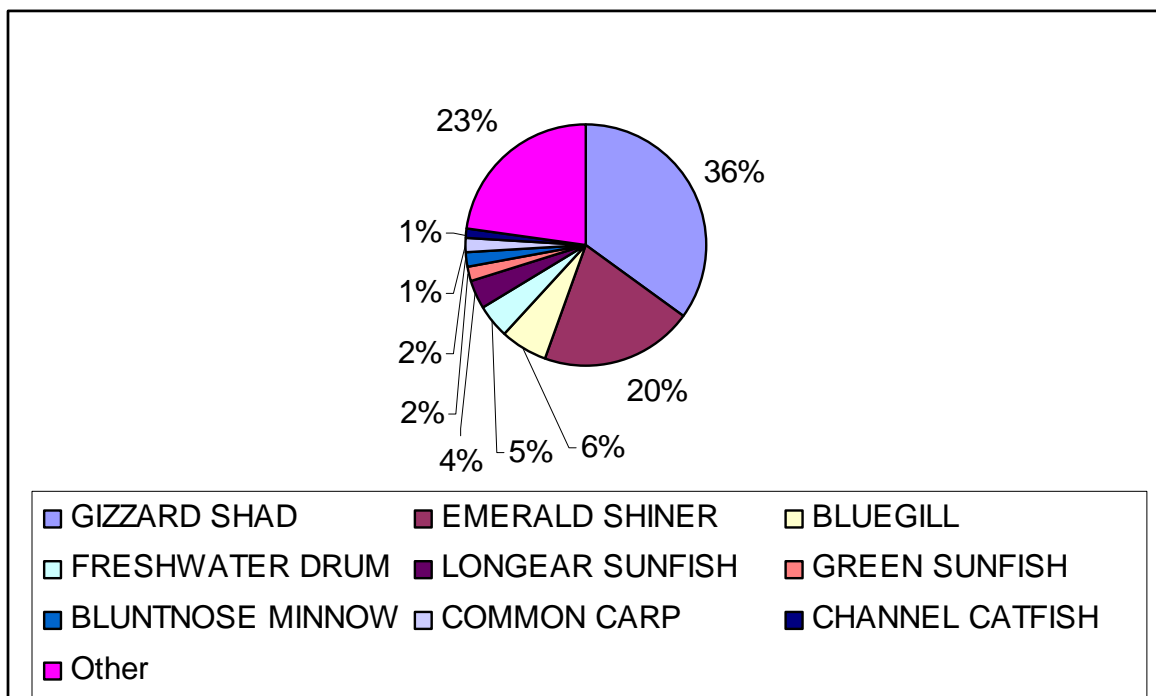


Figure 48. Scioto River proportional fish species composition.

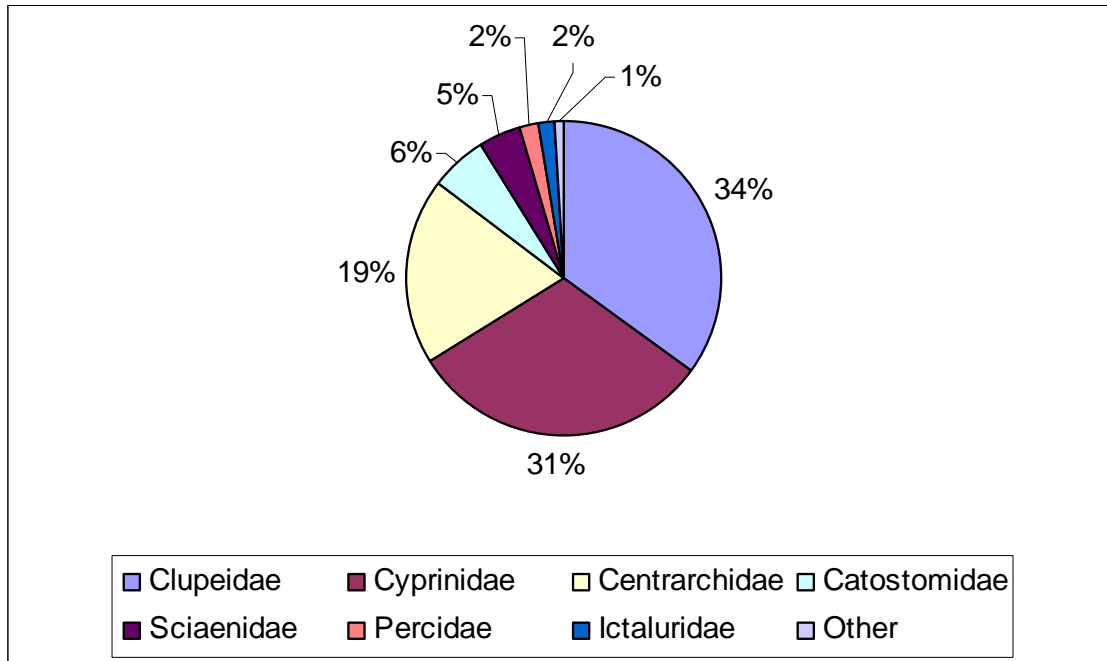


Figure 49. Scioto River proportional fish family composition.

5.2.4.4. MIwb Scores

Modified Index of Well-Being (MIwb) scores were calculated for each of the thirty sites sampled in 2005. The average MIwb score observed was 7.4 and ranged widely from 4.18 to 10.51 (Appendix 5). MIwb scores exhibited a slight decreasing trend from upstream to downstream. This trend is reflected in additional indices (Figure 52) and to a lesser degree in QHEI scores (Figure 47).

5.2.4.5. ICD Scores

Index of Centers of Density (ICD) scores were calculated for each of the thirty sites sampled in 2005. Scores ranged from 0.04 to 5.79. Higher ICD scores (higher densities of unique species) occur primarily within the middle to upper reaches (Figure 52).

5.2.4.6. FAQI Results

Fish Assemblage Quality Index (FAQI) scores were generated for each of the 30 sites on the Scioto River. On a scale of 0 to 1200, the average FAQI score observed was 438 and ranged from 197 to 785, with 50% of the sites scoring below 400 (Figure 50). FAQI scores were not correlated with the stressor gradient observed on the Scioto River ($R = 0.35$, Spearman, $p > 0.27$, Figure 51). FAQI scores were significantly correlated with MIwb ($R = 0.85$, Spearman, $p < 0.001$, Figure 52) and ICD scores ($R = 0.84$, Spearman, $p < 0.001$, Figure 52). FAQI scores were also significantly correlated with OEPA IBI scores ($R = 0.74$, Spearman, $p < 0.02$) even though they were 20 % lower on average (Figure 53).

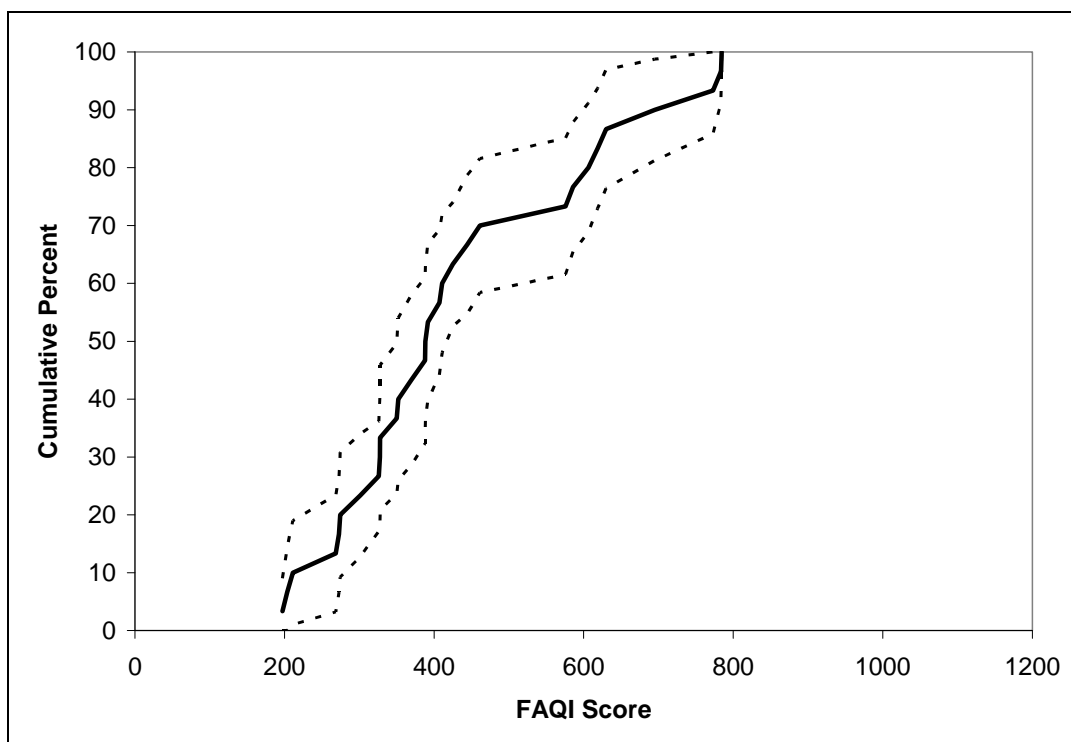


Figure 50. Cumulative distribution function (black line) graph of FAQI scores on the Scioto River (dotted lines = 95% confidence bands).

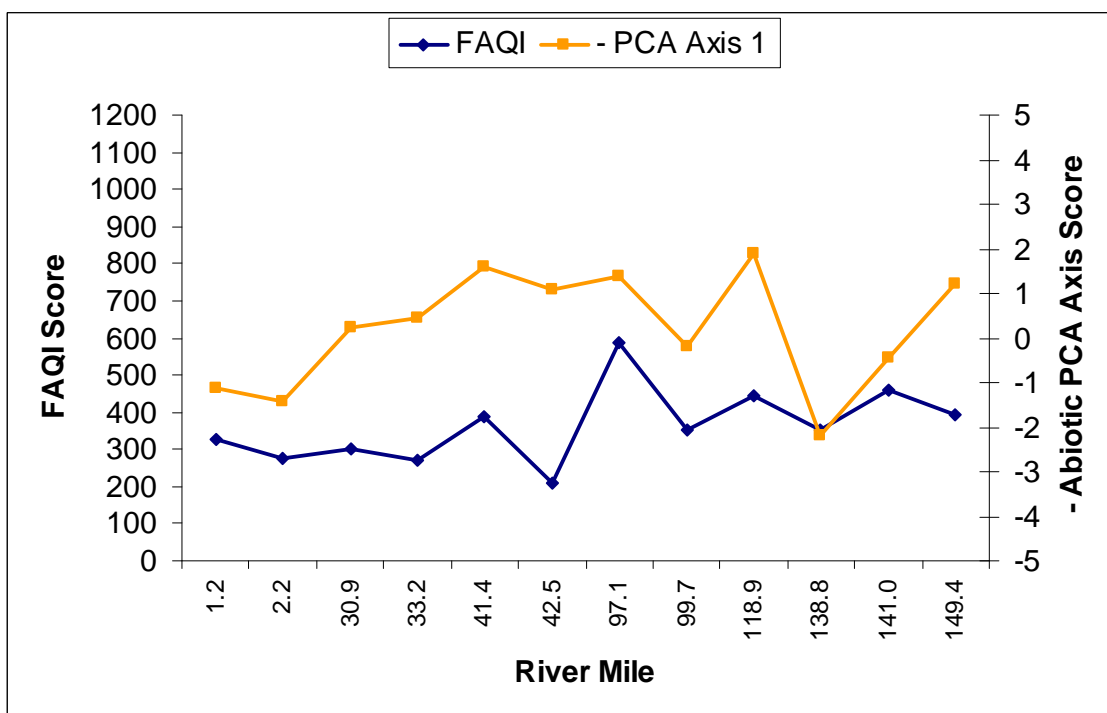


Figure 51. FAQI and the inverse PCA Axis 1 ('+' = good habitat/water quality, '-' = poor habitat/water quality) scores for all Scioto River sites included in the abiotic PCA. River flow is from right to left.

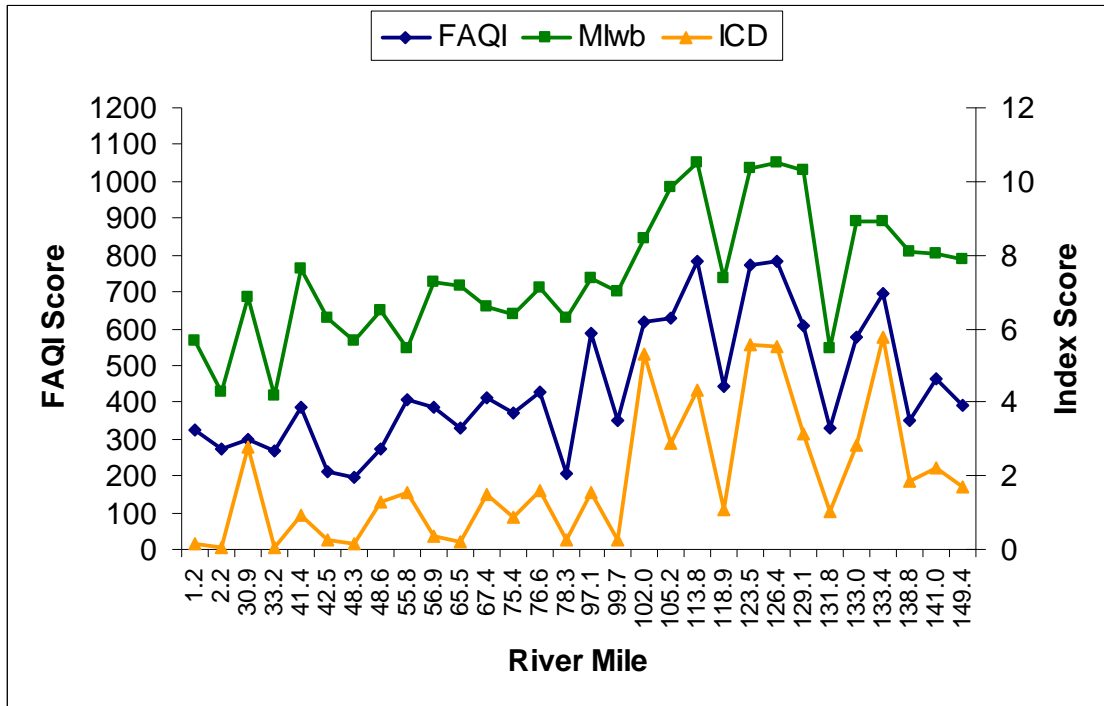


Figure 52. FAQI, MIwb, and ICD scores for all sites sampled on the Scioto River. River flow is from right to left.

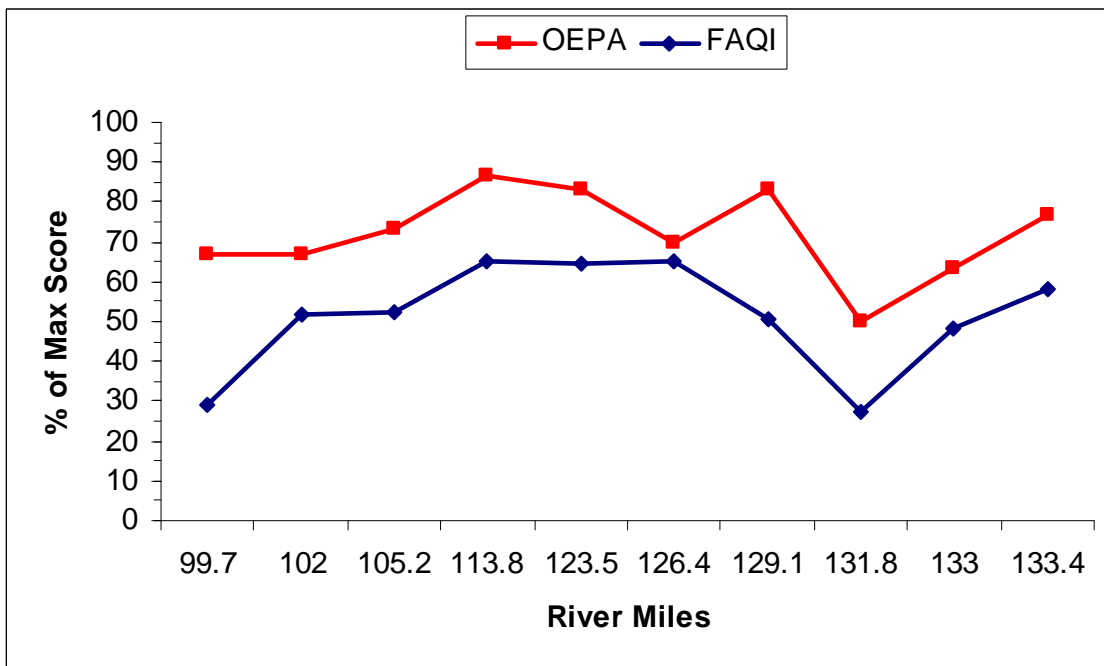


Figure 53. Multimetric index scores (labeled) for the Scioto River produced by Ohio Environmental Protection Agency (OEPA) and ORSANCO (FAQI). River flow is from right to left.

5.2.5. MINNESOTA RIVER

During July 2006, electrofishing and habitat data were collected at 27 sites between river miles 21 and 301. The remaining three sites fell on impoundments in the upper river. As sites in deeper, impounded waters require nighttime sampling, completing the remaining 3 would have required an additional trip from Cincinnati to Minnesota. After discussing the issue with our USEPA project officer, it was decided that the completion of the remaining 3 sites was not worth the effort required and resources should be expended on other rivers. All 27 sites were sampled during the day. During the 2005 index period, water chemistry and nutrient data were collected by USEPA at 6 overlapping sites.

5.2.5.1. Habitat / Water Quality Summary

Intensive physical habitat survey data taken from each of the 27 electrofishing sites revealed benthic substrate composition to be dominated by sand (47%), and to a lesser extent, fines (35%). Coarser substrates combined to comprise 30% of the substrate overall (Figure 54) and, when found, comprised a similar percentage within individual sites (Figure 55). Hardpan comprised only 3% of the substrate (Figure 54). Overall substrate composition remained relatively constant throughout the entirety of the Minnesota River (Figure 55). Submerged aquatic vegetation was present at 4% of the sites. Overhanging vegetation and in-stream woody cover were present at 93% and 96% of the sites respectively (Appendix 5). QHEI and nutrient data were taken from 27 and 6 sites, respectively. The average (SE) QHEI score for the Minnesota River was 58.5 (1.46). Scores varied slightly across sites, with the lowest scores occurring in the middle of the river (Figure 56). Average pH was 7.15 (0.04). Temperature averaged 26.91°C (0.26), and dissolved oxygen content averaged 9.0 mg/L (0.57). The Minnesota River is typically turbid. Conductivity was moderate with an average value of 497.38µs/cm (5.79). Secchi depths averaged 11.22 inches (0.38) (Appendix 5).

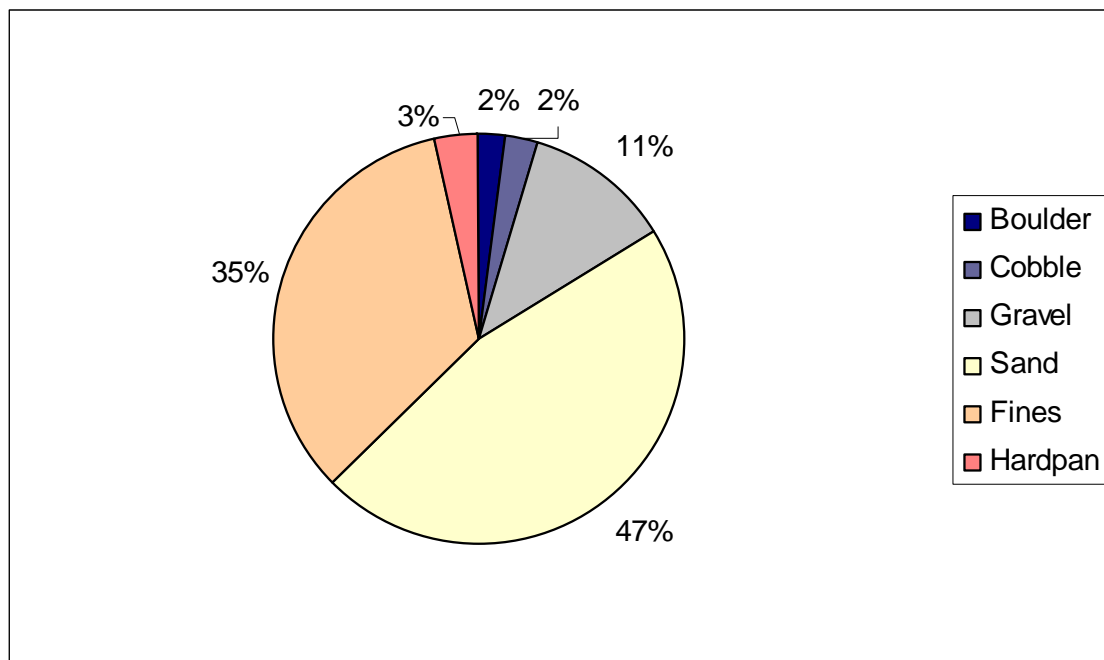


Figure 54. Minnesota River proportional benthic substrate composition.

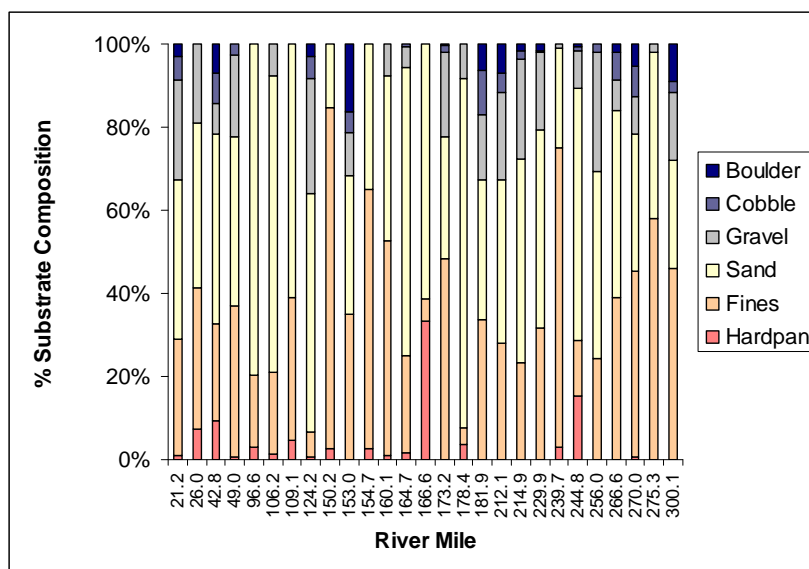


Figure 55. Minnesota River proportional benthic substrate composition at each site. River flow is from right to left.

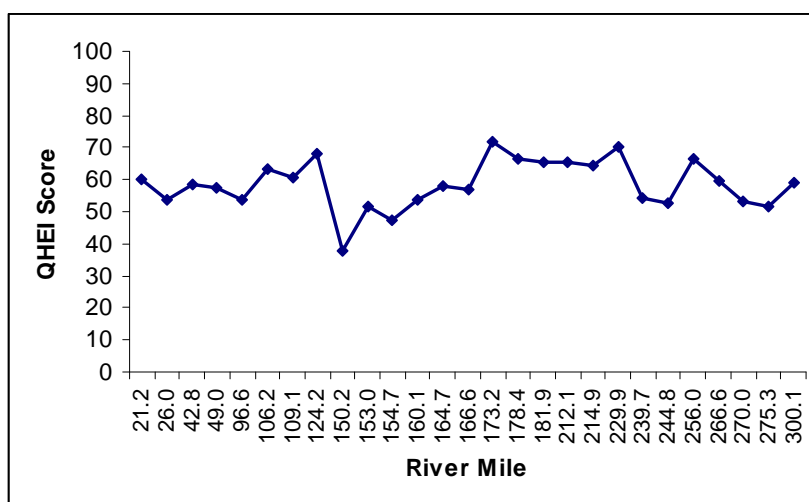


Figure 56. Qualitative habitat evaluation index (QHEI) scores for each river mile sampled on the Minnesota River. River flow is from right to left.

5.2.5.2. T/E and Exotic Species Distribution Summary

The entirety of the Minnesota River lies within the state of Minnesota. All twenty-nine sites sampled along its length were subject to the state's threatened and endangered species list. One species listed in Minnesota, the black buffalo (*Ictibus niger*), was sampled from the Minnesota River (Appendix 5). The black buffalo is considered a species of special concern and was captured at 19% of the sites surveyed. No federally listed threatened or endangered species were sampled on the Minnesota River. Exotic species were collected at 86% of the sites on the Minnesota River. These included 229 common carp (*Cyprinus carpio*) from 25 sites, and 11 white bass / striped bass hybrids from 4 sites. Exotic and T/E species distribution maps are located in Appendix 4.

5.2.5.3. Species Composition / Metrics: Number of species, Number of individuals, electrofishing times

Fish collections from the twenty-seven sites on the Minnesota River in 2006 produced 50 taxa, including hybrids and exotics, representing 11 families (Appendix 5). Average (SE) numbers of species and individuals collected per site were 14.1 (0.6) and 104.1 (10.5), respectively. Sampling effort was measured in seconds, where electrical current was actively applied to the water. The average electrofishing (EF) time expended per site was 1822.9 seconds. Negotiation of varying degrees of in-stream cover and obstructions led to EF time variation within sites.

The most abundant individual species were gizzard shad, emerald shiner, and spotfin shiner accounting for 28%, 14% and 13% of the catch respectively (Figure 57). The ‘other’ species category includes 41 taxa that individually represent < 3% of the total catch. At the family level, Clupeidae was dominant, comprising 46% of the catch (Figure 58). Additionally, suckers (Catostomidae) were a major component, representing 27% of the total composition (Figure 58).

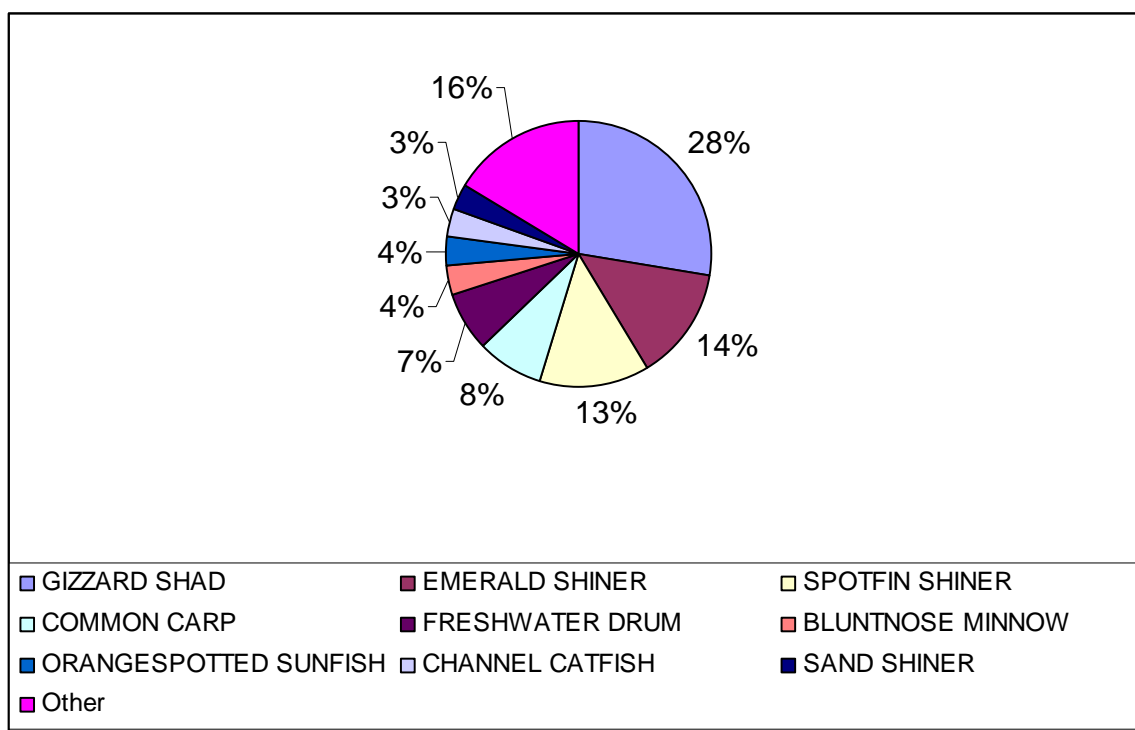


Figure 57. Minnesota River proportional fish species composition.

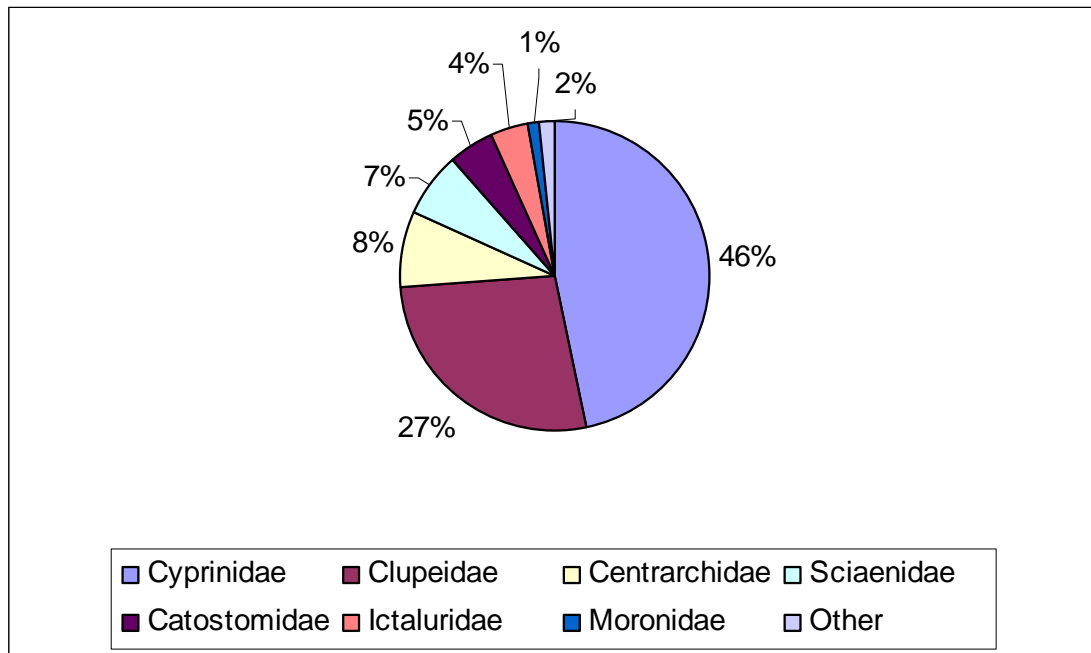


Figure 58. Minnesota River proportional fish family composition.

5.2.5.4. MIwb Scores

Modified Index of Well-Being (MIwb) scores were calculated for each of the twenty-seven sites sampled in 2006. The average MIwb score observed was 5.73 and ranged from 3.36 to 7.79 (Appendix 5). MIwb scores exhibited no trend with respect to river mile (Figure 62). The sporadic higher quality sites, with respect to MIwb, had relatively higher percentages of coarse substrates (Figure 55), whereas extremely low scores occurred at sites with large proportions of fines.

5.2.5.5. ICD Scores

Index of Centers of Density (ICD) scores were calculated for each of the twenty-seven sites sampled in 2006. Scores ranged from 0.44 to 5.02. When multiplied by a factor of 10 to improve resolution, increasing ICD scores (higher densities of unique species) were of sporadic distribution (Figure 61).

5.2.5.6. FAQI Results

Fish Assemblage Quality Index (FAQI) scores were generated for each of the 30 sites on the Minnesota River. On a scale of 0 to 1200, the average FAQI score observed was 307 and ranged from 101 to 484, with approximately 50% of the sites scoring between 300 and 400 (Figure 59). FAQI scores were not correlated with the observed stressor gradient ($R = 0.21$, Spearman, $p > 0.32$, Figure 60). However, FAQI scores were significantly correlated with both MIwb ($R = 0.53$, Spearman, $p < 0.005$, Figure 61) and ICD scores ($R = 0.59$, Spearman, $p < 0.002$, Figure 61). MDNR IBI scores and FAQI scores were not correlated ($R = 0.44$, Spearman, $p > 0.20$), and FAQI scores were 30% lower (Figure 62).

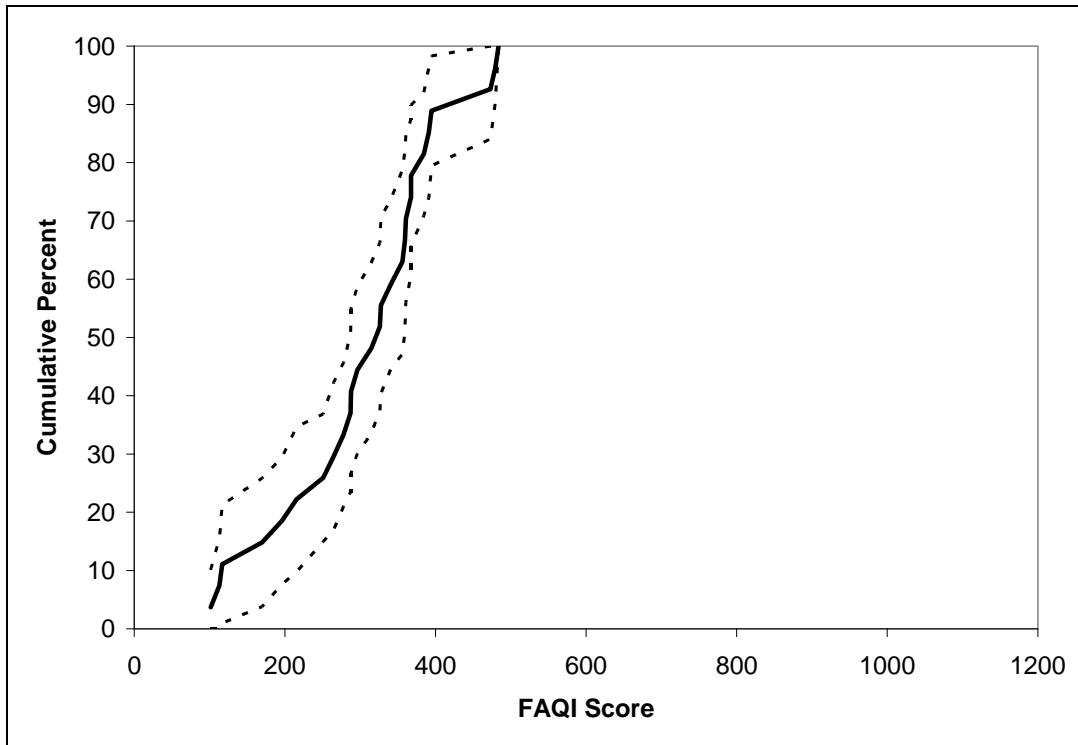


Figure 59. Cumulative distribution function (black line) graph of FAQI scores on the Minnesota River (dotted lines = 95% confidence bands).

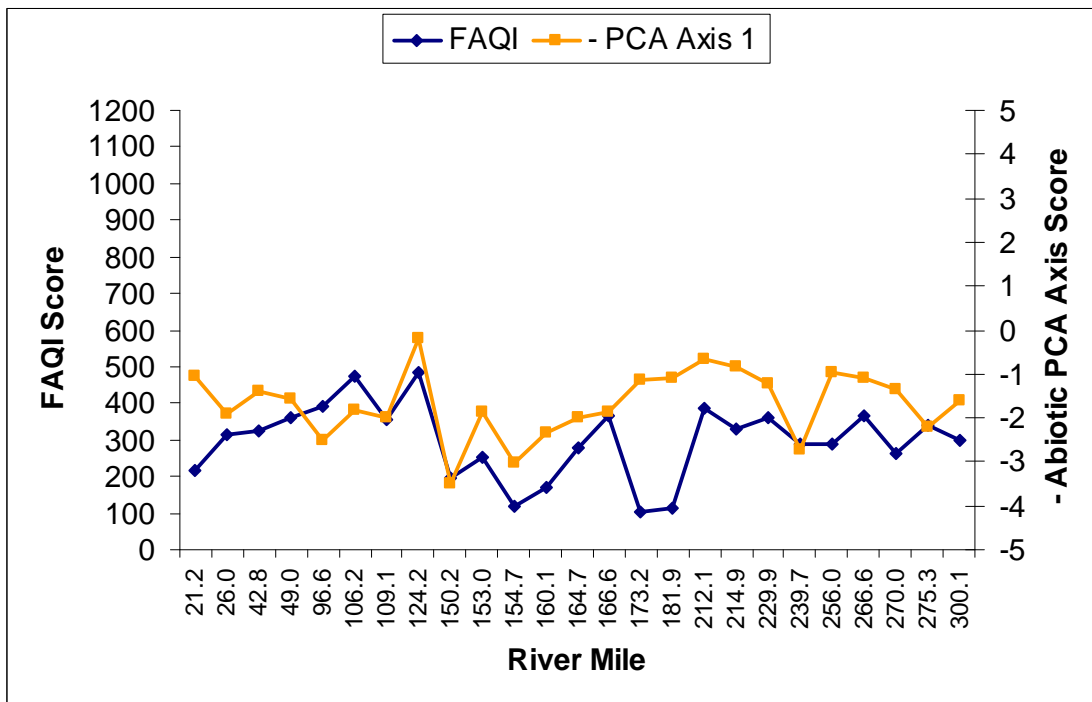


Figure 60. FAQI and the inverse PCA Axis 1 ('+' = good habitat/water quality, '-' = poor habitat/water quality) scores for all Minnesota River sites included in the abiotic PCA. River flow is from right to left.

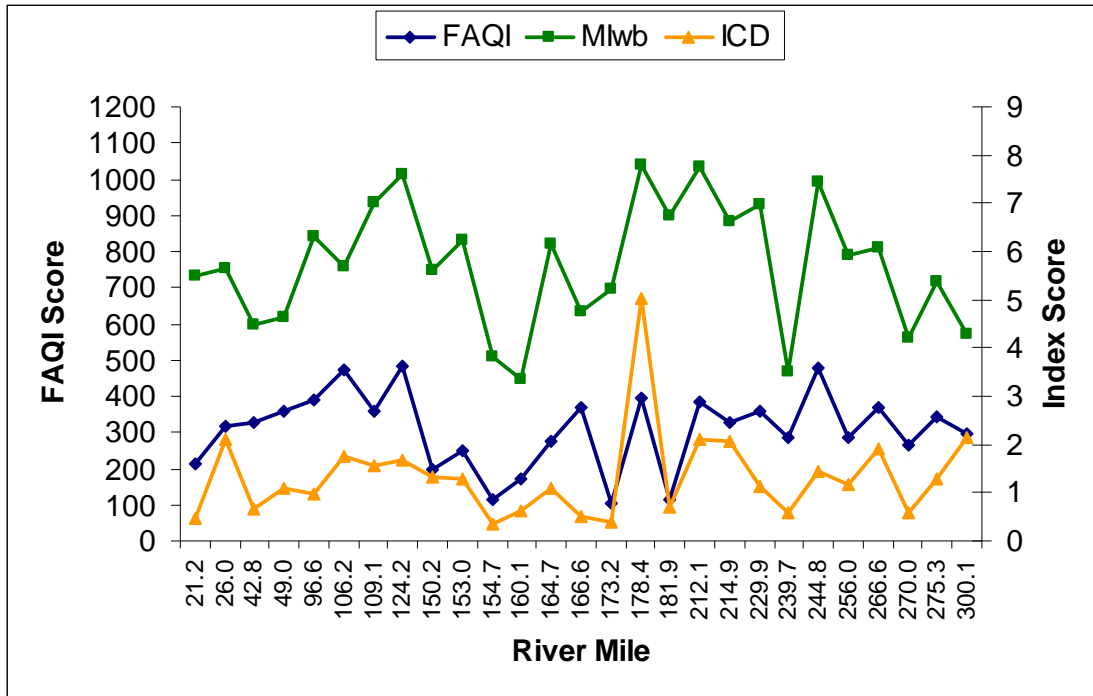


Figure 61. FAQI, MIwb, and ICD scores for all sites sampled on the Minnesota River. River flow is from right to left.

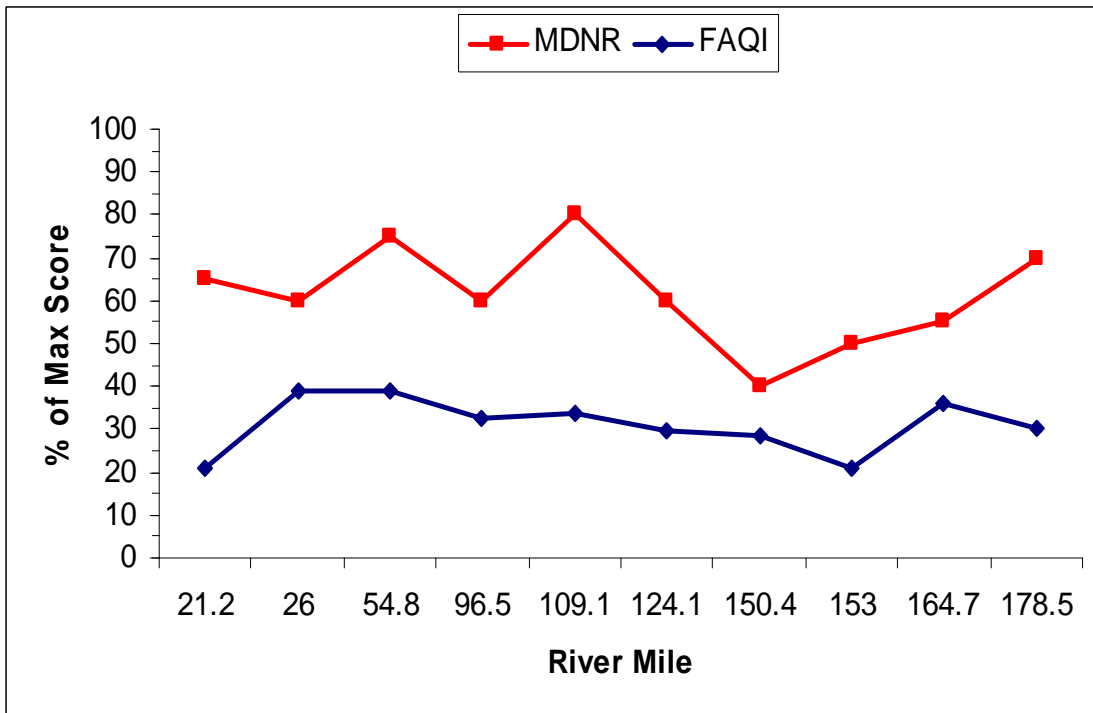


Figure 62. Multimetric index scores (labeled) for the Minnesota River produced by Minnesota Department of Natural Resources (MDNR) and ORSANCO (FAQI). River flow is from right to left.

5.2.6. MUSKINGUM RIVER

Between August and September 2006, electrofishing and habitat data were collected at 30 sites between river miles 27 and 178. Nine sites were sampled at night on the Muskingum River mainstem, and the remaining 21 sites were sampled during the day. No water chemistry or nutrient data were collected.

5.2.6.1 Habitat / Water Quality Summary

Intensive physical habitat survey data taken from each of the thirty electrofishing sites revealed benthic substrate composition to be dominated by sand. Coarser substrates combined to comprise 44% of the substrate (Figure 63) and were regularly distributed throughout the river (Figure 64). Fines and hardpan comprised 10% and 3% respectively (Figure 63). These two substrate types also provided the most variation throughout the river, with fines increasing towards the mouth and hardpan increasing towards the source. No submerged aquatic vegetation was present at the 9 sites where it was recorded. Overhanging vegetation and in-stream woody cover were both present all of the 9 sites where it was recorded (Appendix 5). QHEI data were taken from 30 sites. The average (SE) QHEI score for the Muskingum River was 67.2 (2.41). Scores fluctuated, but generally increased towards the source of the river (Figure 65). Average pH was 9.92 (0.40). Temperature averaged 24.87°C (0.46), and dissolved oxygen content averaged 9.0 mg/L (0.26). Conductivity was moderate with an average value of 499.18 $\mu\text{S}/\text{cm}$ (37.10). Secchi depths averaged 48.34 inches (3.43) (Appendix 5).

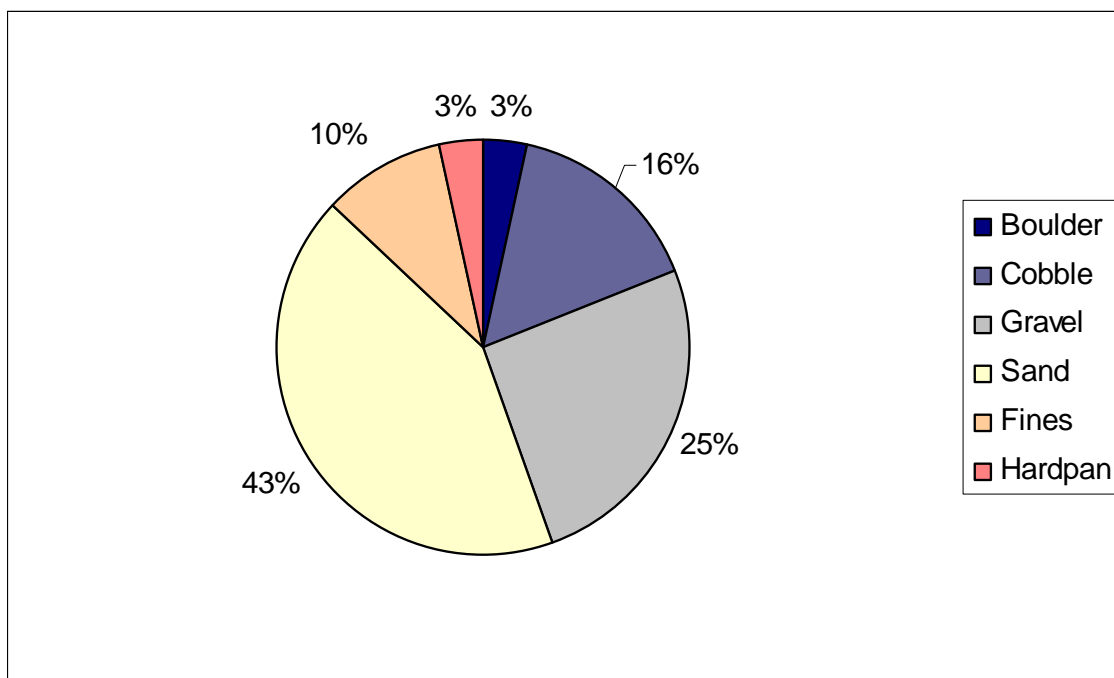


Figure 63. Muskingum River proportional benthic substrate composition.

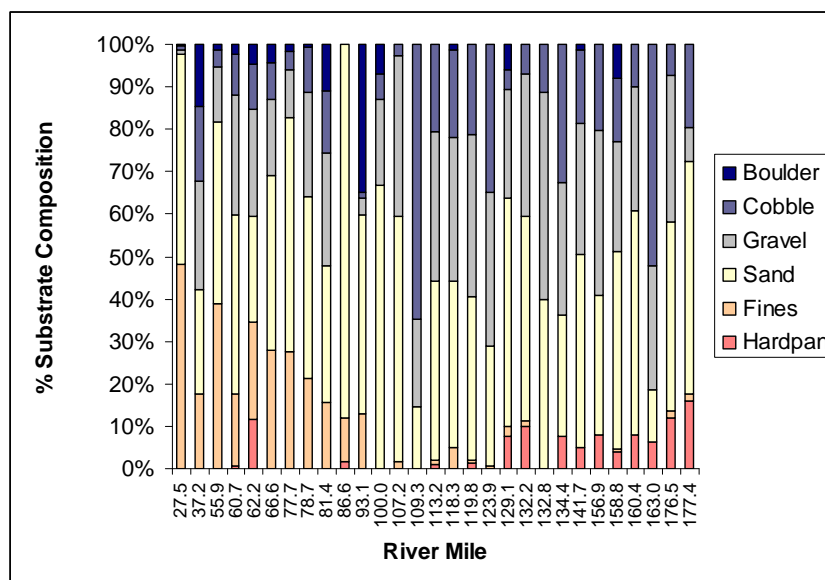


Figure 64. Muskingum River proportional benthic substrate composition at each site. River flow is from right to left.

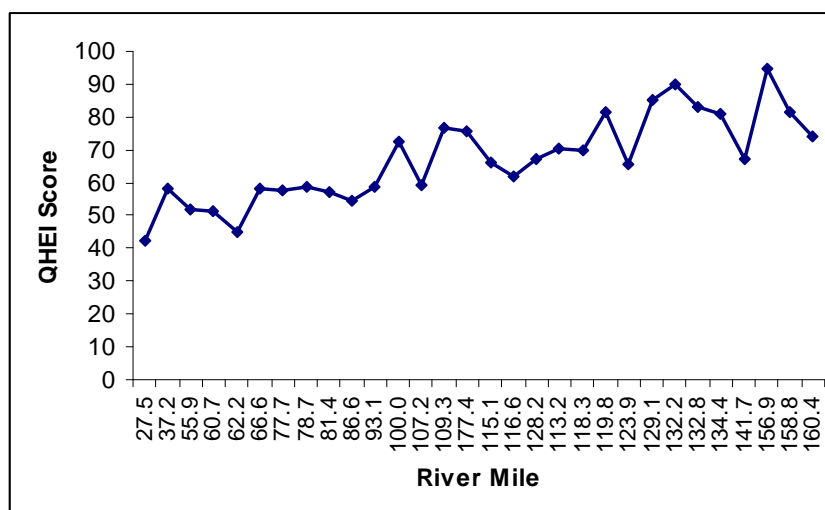


Figure 65. Qualitative habitat evaluation index (QHEI) scores for each river mile sampled on the Muskingum River. River flow is from right to left.

5.2.6.2. T/E and Exotic Species Distribution Summary

The entirety of the Muskingum River lies within the state of Ohio. All thirty sites sampled along its length were subject to the state's threatened and endangered species list. Four species listed in Ohio were sampled from the Muskingum River: the endangered mountain madtom (*Noturus eleutherus*) and blacknose shiner (*Notropis heterolepis*), the threatened bluebreast darter (*Etheostoma camurum*), and the river redhorse (*Moxostoma carinatum*), a species of special concern. *Moxostoma carinatum* and *E. camurum* were captured at multiple sites and were the most abundant with 16 and 11 individuals respectively. Two *Noturus eleutherus* were captured from a single site, while only one *Notropis heterolepis* was captured during the entirety of the study. Overall, 26% of the sites surveyed on the Muskingum River contained state-listed species (Appendix 5). No federally listed threatened or endangered species were captured on the

Muskingum River. Exotic species were collected at 93% of sites on the Muskingum River. These included 177 common carp (*Cyprinus carpio*) from 27 sites, 1 goldfish (*Carassius auratus*) from 1 site, 6 redear sunfish (*Lepomis microlophus*) from 3 sites, 3 striped bass (*Morone saxatilis*) from 1 site, and 3 western mosquitofish (*Gambusia affinis*) from 1 site. T/E and exotic species distribution maps are located in Appendix 4.

5.2.6.3. Species Composition / Metrics; Number of species, Number of individuals, electrofishing times

Fish collections from the thirty sites on the Muskingum river in 2006 produced 68 taxa, including hybrids and exotics, representing 15 families (Appendix 5). Average (SE) numbers of species and individuals collected per site were 20.9 (0.6) and 201.7 (14.9) respectively. Sampling effort was measured in seconds, where electrical current was actively applied to the water. The average electrofishing (EF) time expended per site was 2172 seconds. Negotiation of varying degrees of in-stream cover and obstructions led to EF time variation within sites. Likewise, heterogeneous in-stream cover produced variation in fish collections between sites.

The most abundant individual species was spotfin shiner, accounting for 12% of the catch (Figure 66). The 'other' species category includes 59 taxa that individually represent < 4% of the total catch. At the family level, Cyprinidae was dominant, comprising 40% of the catch (Figure 67). Additionally, suckers (Catostomidae) were a major component, representing 24% of the total composition (Figure 67).

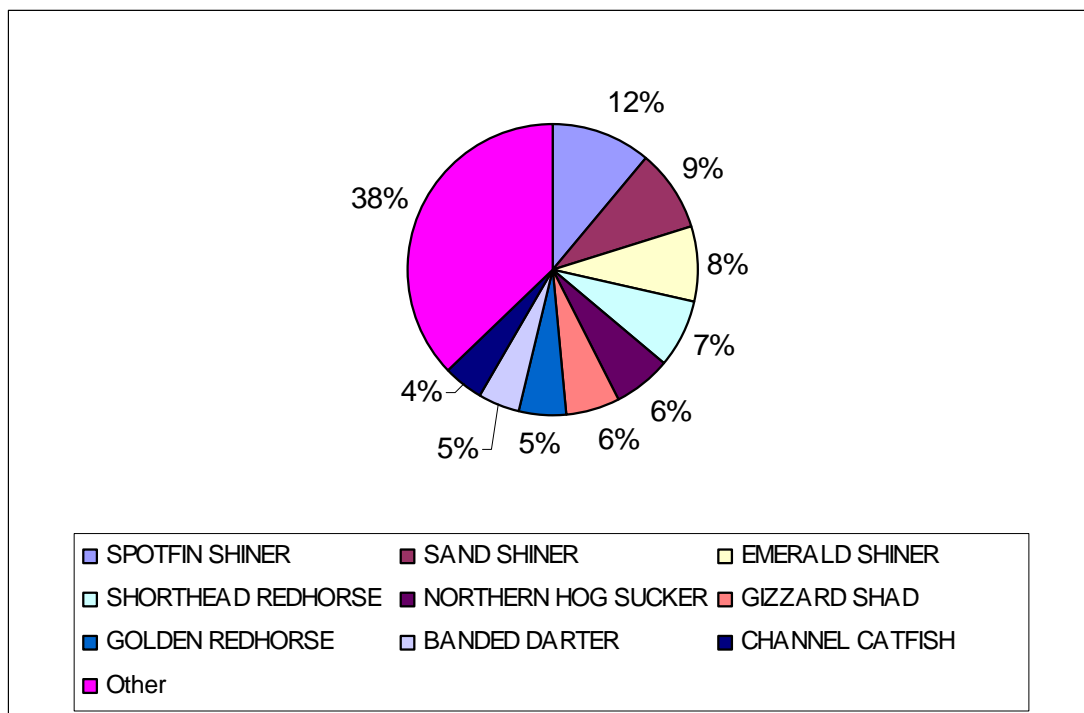


Figure 66. Muskingum river proportional fish species composition.

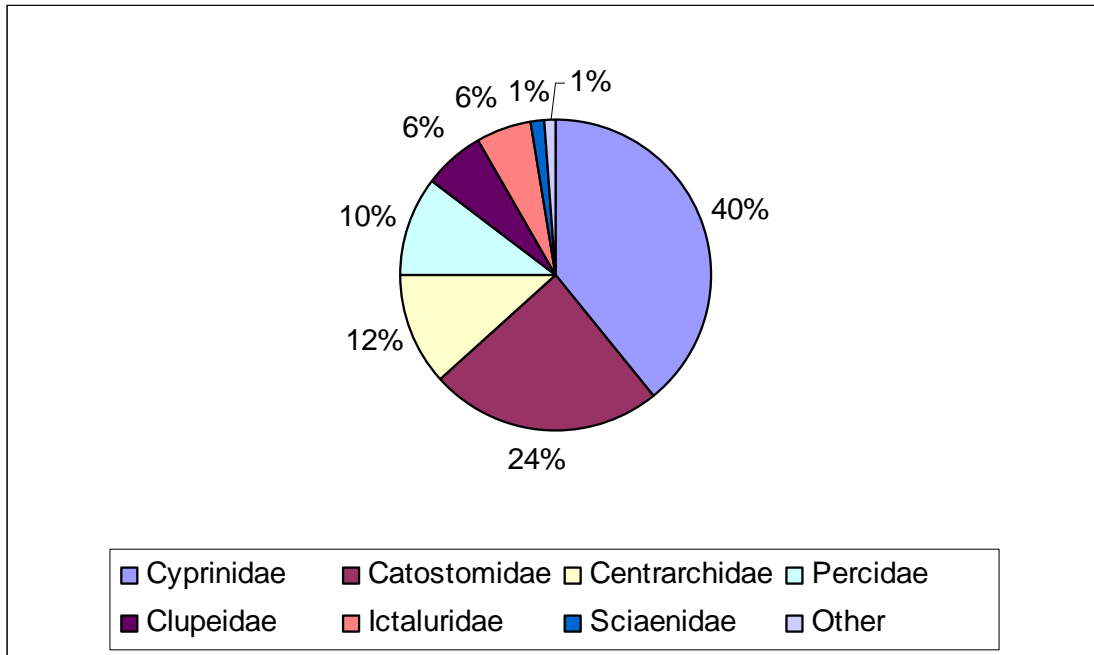


Figure 67. Muskingum river proportional fish family composition.

5.2.6.4. MIwb Scores

Modified Index of Well-Being (MIwb) scores were calculated for each of the thirty sites sampled in 2006. The average MIwb score observed was 8.12 and ranged from 6.34 to 9.37 (Appendix 5). MIwb scores exhibited no trend with respect to river mile. High quality sites were frequently encountered throughout the length of the river.

5.2.6.5. ICD Scores

Index of Centers of Density (ICD) scores were calculated for each of the thirty sites sampled in 2006. Scores ranged from 0.44 to 4.41. Higher ICD scores (higher densities of unique species) were encountered more frequently in the lower reaches of the river (Figure 69).

5.2.6.6. FAQI Results

Fish Assemblage Quality Index (FAQI) scores were generated for each of the 30 sites on the Muskingum River. On a scale of 0 to 1200, the average FAQI score observed was 699 and ranged from 282 to 950, with 20% of the sites scoring above 900 (Figure 68). FAQI scores were significantly correlated with the observed stressor gradient ($R = 0.87$, Spearman, $p < 0.001$, Figure 69). FAQI scores were also correlated with MIwb scores ($R = 0.55$, Spearman, $p < 0.002$, Figure 70), but not with ICD scores ($R = 0.21$, Spearman, $p > 0.25$, Figure 70). However, unlike the other two indices, FAQI exhibited a trend with respect to river mile (Figure 70). FAQI scores increased with river mile, likely due to a similar pattern observed in instream habitat (Figure 64). FAQI scores were not correlated with the IBI scores provided by OEPA ($R = 0.37$, Spearman, $p > 0.46$, Figure 71).

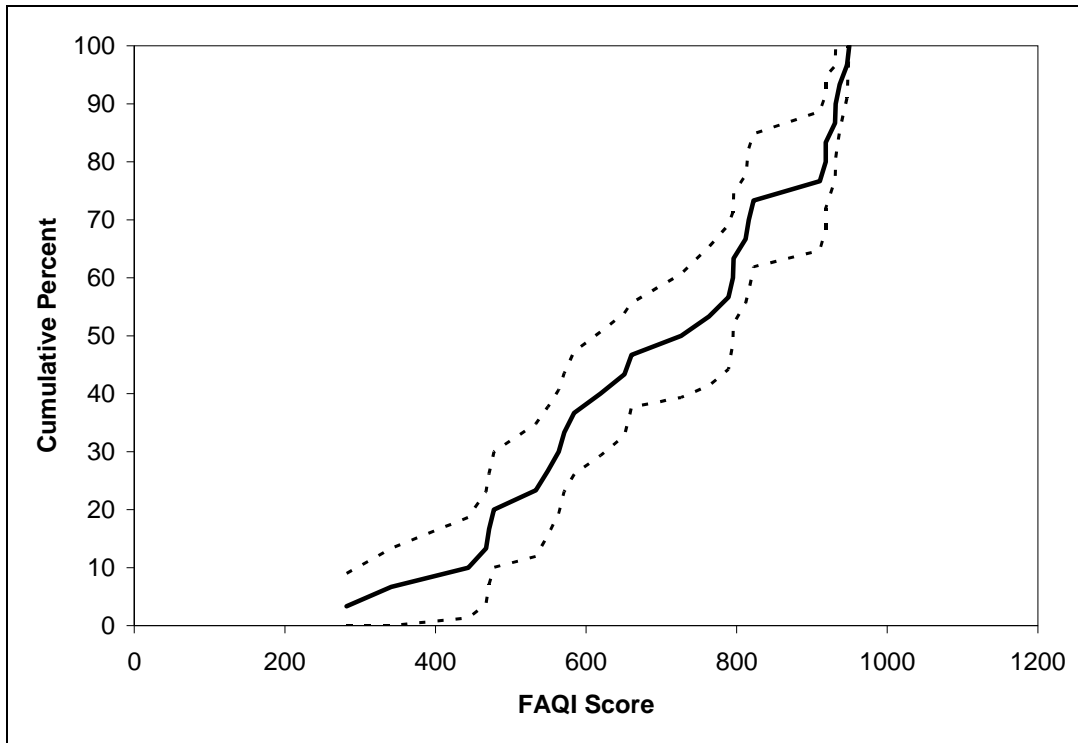


Figure 68. Cumulative distribution function (black line) graph of FAQI scores on the Muskingum River (dotted lines = 95% confidence bands).

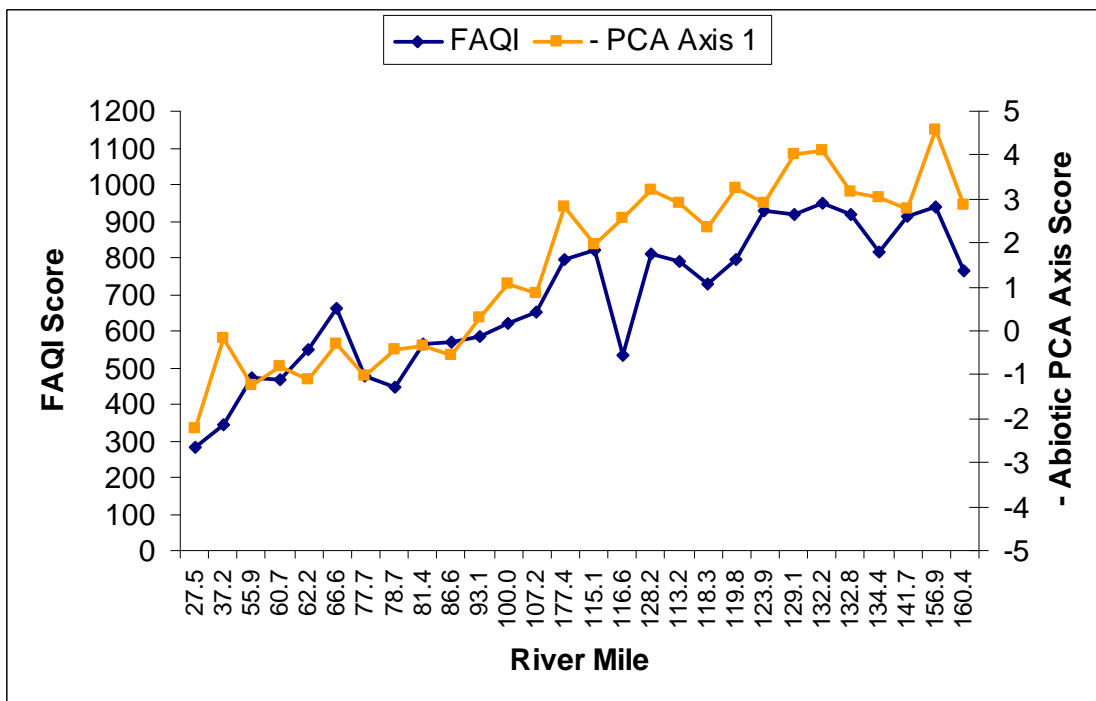


Figure 69. FAQI and the inverse PCA Axis 1 ('+' = good habitat/water quality, '-' = poor habitat/water quality) scores for all Muskingum River sites included in the abiotic PCA. River flow is from right to left.

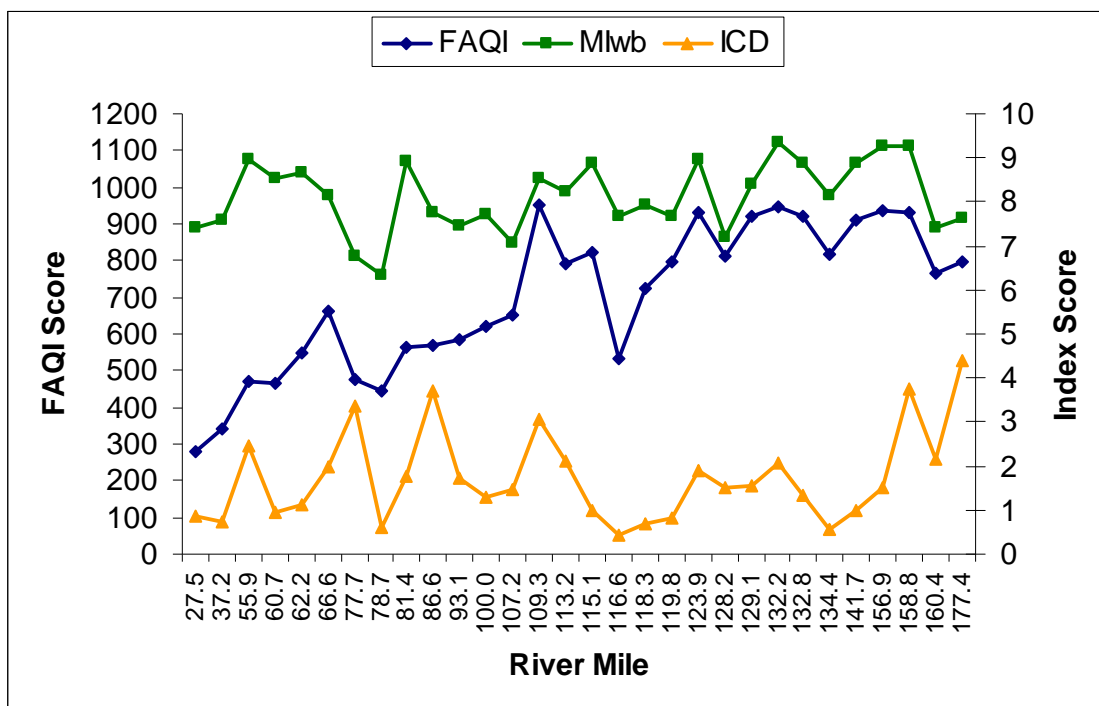


Figure 70. FAQI, MIwb, and ICD scores for all sites sampled on the Muskingum River. River flow is from right to left.

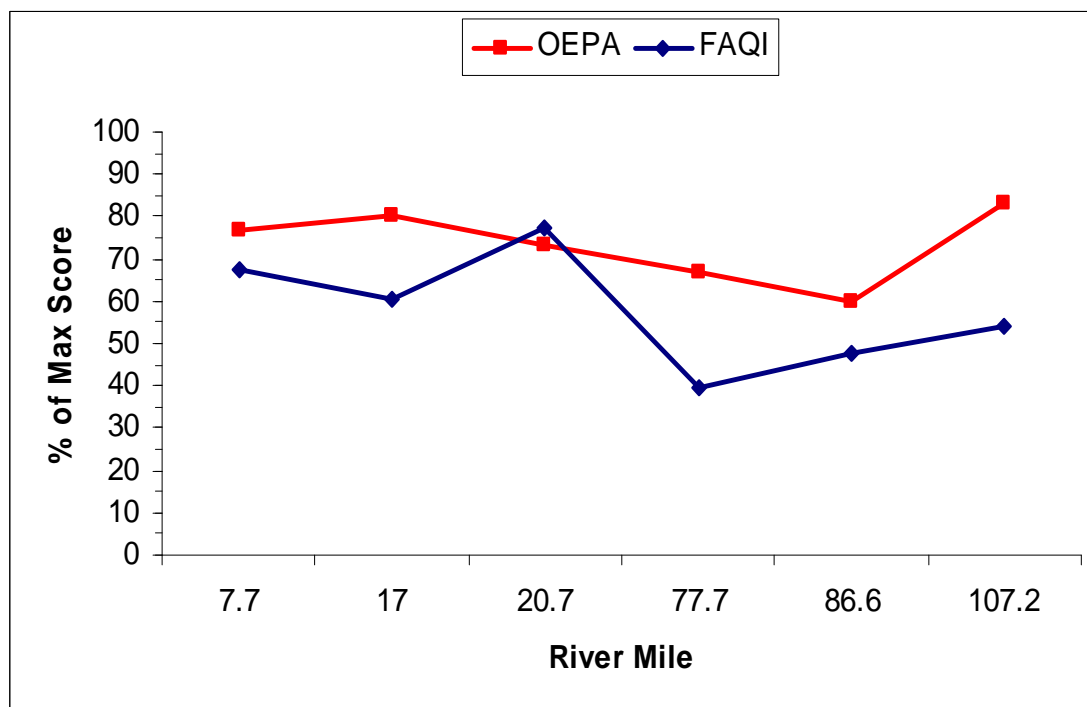


Figure 71. Multimetric index scores (labeled) for the Muskingum River produced by Ohio Environmental Protection Agency (OEPA) and ORSANCO (FAQI). River flow is from right to left.

5.2.7. ILLINOIS RIVER

Between August and October 2006, electrofishing and habitat data were collected at 30 sites between river miles 14 and 299. Of the thirty sites, 27 were sampled at night and three were sampled during the day. During the 2005 index period, water chemistry and nutrient data were collected by USEPA at 23 overlapping sites.

5.2.7.1. Habitat / Water Quality Summary

Intensive physical habitat survey data taken from 27 of the thirty electrofishing sites revealed benthic substrate composition to be dominated by a combination of sand and fines (78%, Figure 72). Coarser substrates combined to comprise 18% of the substrate (Figure 72) and were found in largest percentages near the source of the river (Figure 73). Hardpan comprised 4% (Figure 72). Submerged aquatic vegetation was present at 4% of the sites. Overhanging vegetation and in-stream woody cover were present at 73% and 62% of the sites respectively (Appendix 5). QHEI and nutrient data were taken from 29 and 23 sites respectively. The average (SE) QHEI score for the Illinois River was 49.9 (1.75). Scores remained relatively constant throughout the river, with a strong peak occurring near the source (Figure 74). Average pH was 7.37 (0.63). Temperature averaged 19.08°C (0.74), and dissolved oxygen content averaged 11.0 mg/L. Turbid conditions were typical of the Illinois River. Conductivity was high, with an average value of 750.46 µs/cm (6.47). Secchi depths averaged 19.36 inches (1.15) (Appendix 5).

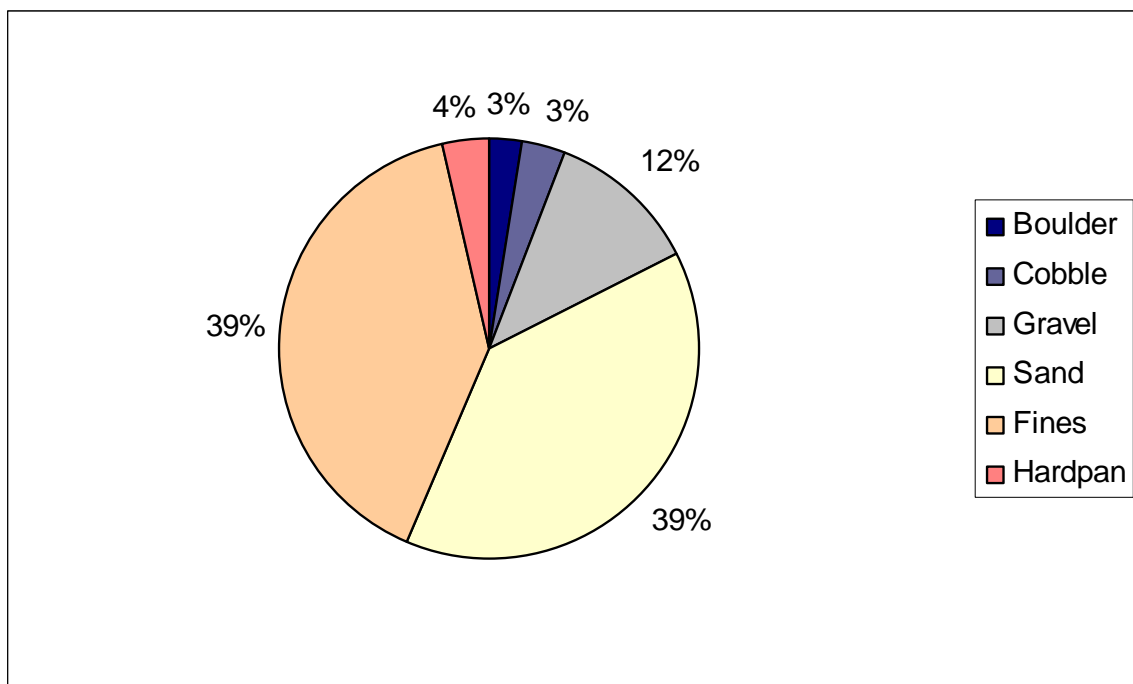


Figure 72. Illinois River proportional benthic substrate composition.

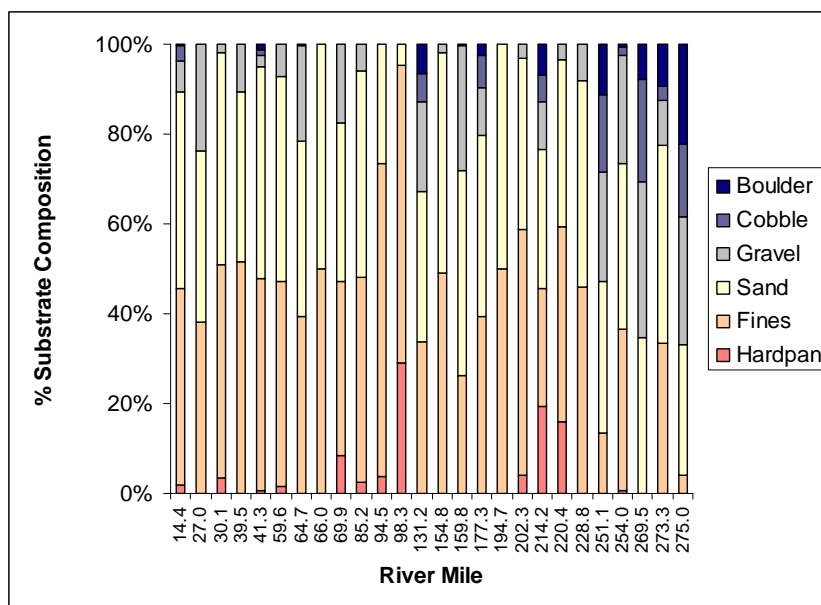


Figure 73. Illinois River proportional benthic substrate composition at each site. River flow is from right to left.

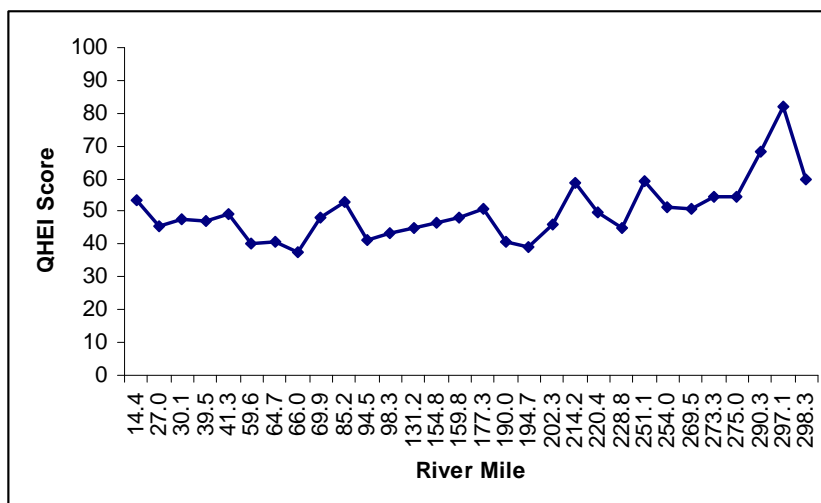


Figure 74. Qualitative habitat evaluation index (QHEI) scores for each river mile sampled on the Illinois River. River flow is from right to left.

5.2.7.2. T/E and Exotic Species Distribution Summary

The entirety of the Illinois River lies within the state of Illinois. All thirty sites sampled along its length were subject to the state's threatened and endangered species list. No state or federally listed threatened or endangered species were sampled from the Illinois River (Appendix 5). Exotic species were collected at 100% of the sites on the Illinois River. These included 1 common carp / goldfish hybrid at one site, 424 common carp (*Cyprinus carpio*) at 29 sites, 3 goldfish (*Carassius auratus*) at 2 sites, 14 grass carp (*Ctenopharyngodon idella*) at 8 sites, 26 white bass / striped bass hybrids at 15 sites, 47 silver carp (*Hypophthalmichthys molitrix*) from 11 sites, 1 striped bass (*Morone saxatilis*) from 1 site, 32 western mosquitofish (*Gambusia affinis*) at 3 sites, and 1 white perch (*Morone americana*) from one site. It is important to note that while

only 47 silver carp were netted throughout the survey, when they were encountered, for every one fish netted, 20+ were observed but not netted. Exotic species distribution maps are located in Appendix 4.

5.2.7.3. Species Composition / Metrics; Number of species, Number of individuals, electrofishing times

Fish collections from the thirty sites on the Illinois River in 2006 produced 68 taxa, including hybrids and exotics, representing 14 families (Appendix 4). Average (SE) numbers of species and individuals collected per site were 17.2 (0.8) and 309.1 (25.6), respectively. Sampling effort was measured in seconds, where electrical current was actively applied to the water. The average electrofishing (EF) time expended per site was 2108.7 seconds. Negotiation of varying degrees of in-stream cover and obstructions led to EF time variation within sites. Likewise, heterogeneous in-stream cover produced variation in fish collections between sites.

The most abundant individual species was gizzard shad, accounting for 35% of the catch (Figure 75). Combined with freshwater drum (19%), the two species comprised over half of the total catch. The 'other' species category includes 59 taxa that individually represented < 2% of the total catch. At the family level, Clupeidae was dominant, comprising 35% of the catch (Figure 76). Additionally, Sciaenidae and Cyprinidae were major components, representing 19% and 16% of the total composition, respectively (Figure 76).

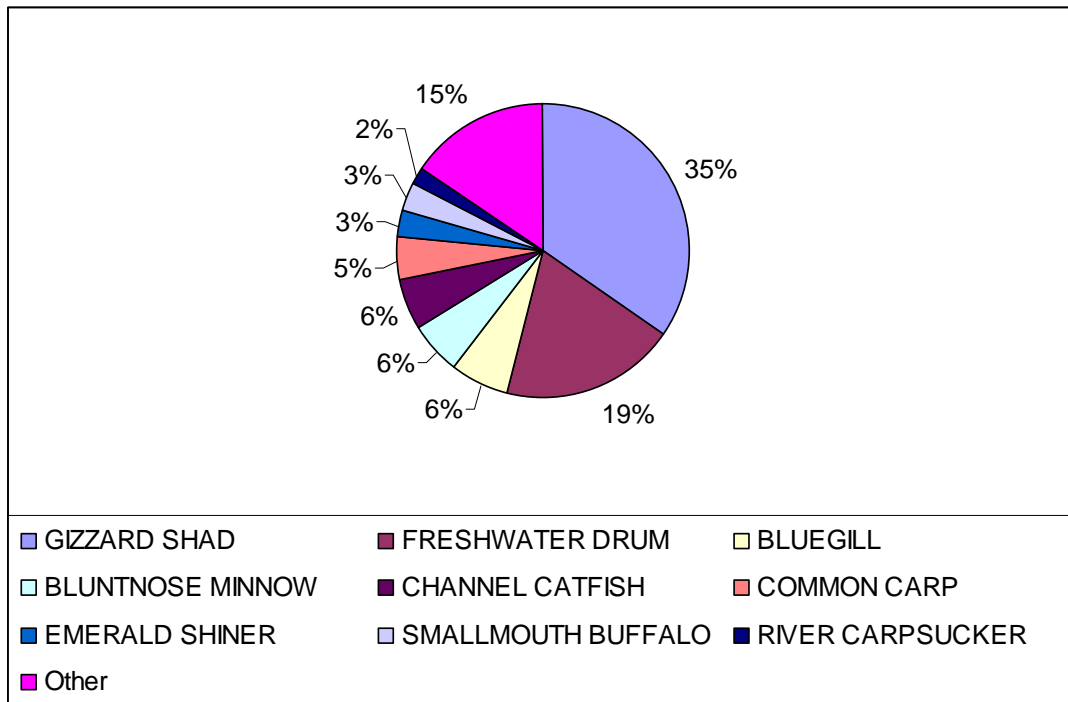


Figure 75. Illinois River proportional fish species composition.

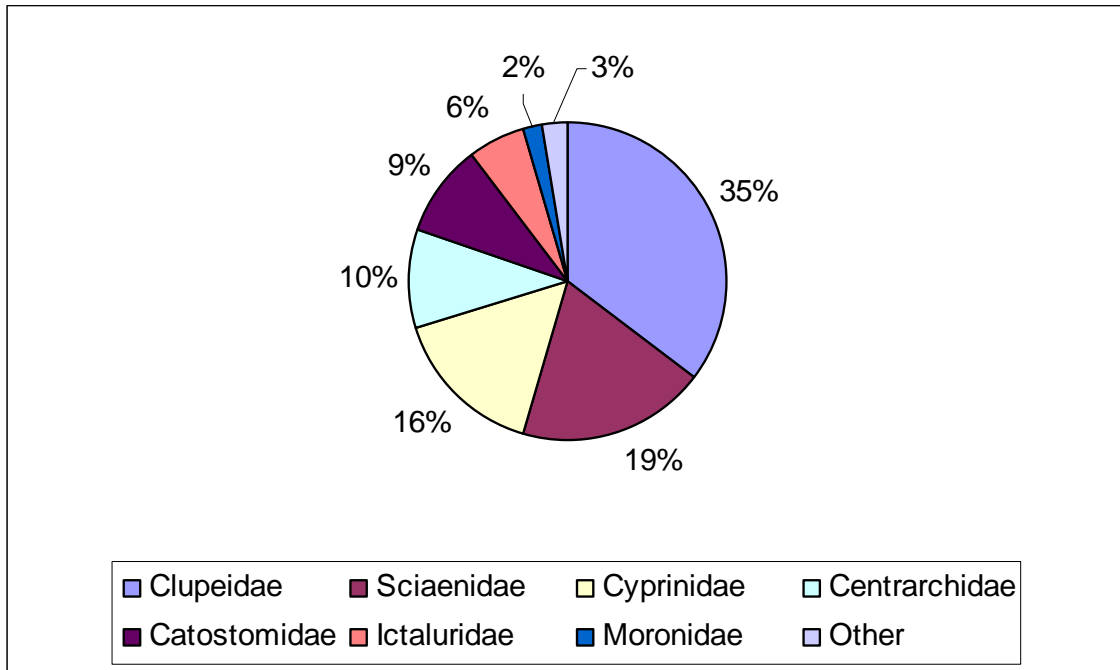


Figure 76. Illinois River proportional fish family composition.

5.2.7.4. MIwb Scores

Modified Index of Well-Being (MIwb) scores were calculated for each of the thirty sites sampled in 2006. The average MIwb score observed was 6.8 and ranged from 4.59 to 9.39 (Appendix 4). Higher quality sites were encountered in the upper reaches of the river, a pattern observed in the other indices, which is likely a representation of the coarser, higher quality instream habitat that exists in the upper reaches of the river (Figure 73).

5.2.7.5. ICD Scores

Index of Centers of Density (ICD) scores were calculated for each of the twenty-nine sites sampled in 2006. Scores ranged from 0.13 to 5.16. Higher ICD scores (higher densities of unique species) were more frequently encountered in the uppermost reaches (Figure 79).

5.2.7.6. FAQI Results

Fish Assemblage Quality Index (FAQI) scores were generated for each of the 30 sites on the Illinois River. On a scale of 0 to 1200, the average FAQI score observed was 271 and ranged from 85 to 589, with 60% of the sites scoring less than 300 (Figure 77). FAQI scores were not correlated with the observed stressor gradient ($R = 0.31$, Spearman, $p > 0.31$, Figure 78). However, FAQI scores were significantly correlated with both MIwb ($R = 0.83$, Spearman, $p < 0.001$, Figure 79) and ICD scores ($R = 0.82$, Spearman, $p < 0.001$, Figure 79). No comparisons could be made between FAQI scores and other multimetric indices as none are currently in use on the Illinois River.

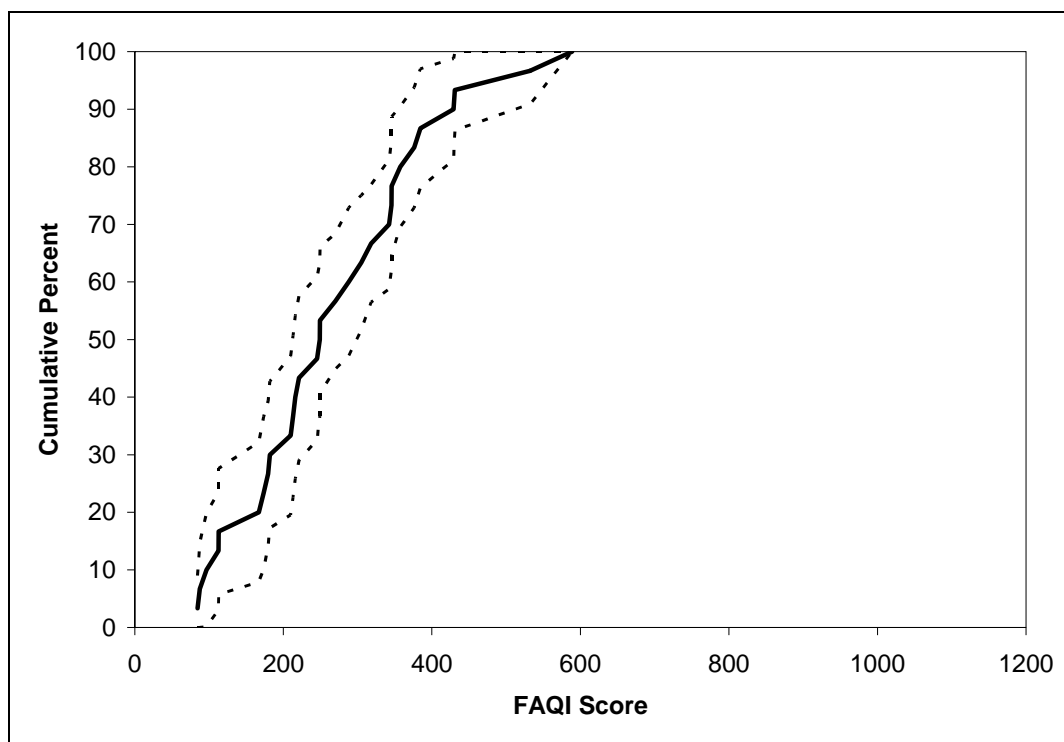


Figure 77. Cumulative distribution function (black line) graph of FAQI scores on the Illinois River (dotted lines = 95% confidence bands).

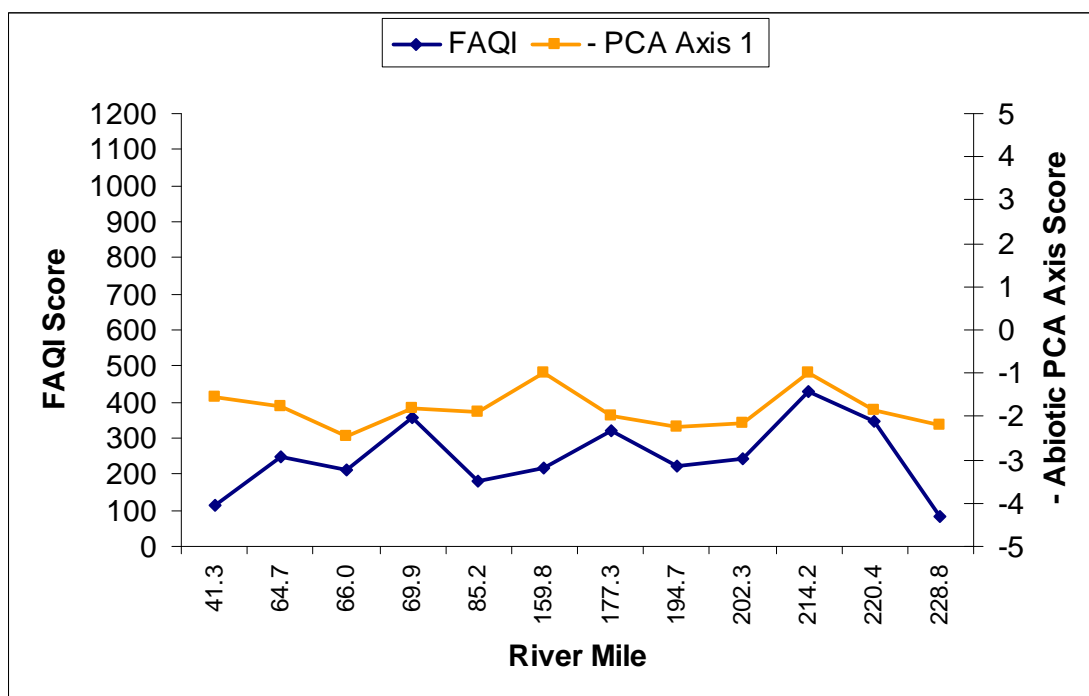


Figure 78. FAQI and the inverse PCA Axis 1 ('+' = good habitat/water quality, '-' = poor habitat/water quality) scores for all Illinois River sites included in the abiotic PCA. River flow is from right to left.

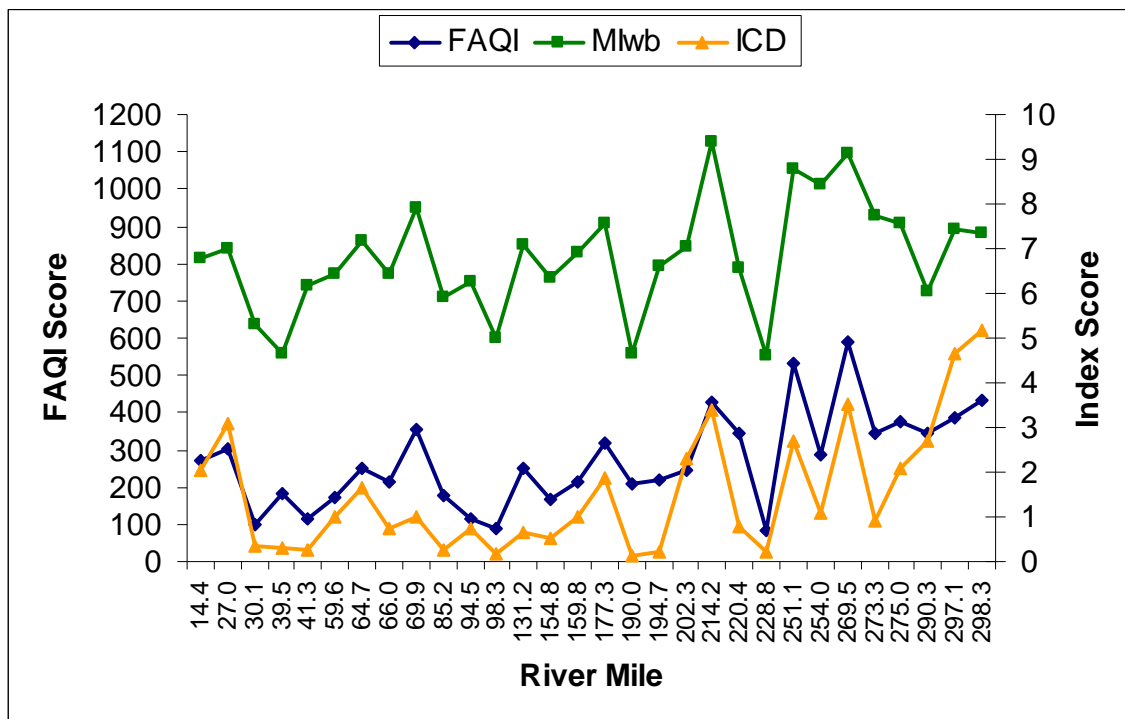


Figure 79. FAQI, MIwb, and ICD scores for all sites sampled on the Illinois River. River flow is from right to left.

5.3. INTRA-RIVER COMPARISON RESULTS

Instream abiotic habitat component PCA Axis 1 and FAQI score were plotted against river mile to demonstrate individual longitudinal changes in water quality and biology along the length of each river. The goal of these analyses was to document abiotic and biological condition gradients within each river.

5.3.1. Abiotic Trends

Abiotic habitat PCA analyses were plotted against ascending river mile to demonstrate the presence/ absence of a functional disturbance gradient within individual rivers. It is important to note that each plot is scaled to a uniform distance of 400 river miles as this was the greatest distance of any of the rivers sampled (Wabash). As a result, existing trends on rivers of lesser lengths are respectively compressed and therefore appear amplified.

It is not possible, given the data available for this study, to track and discuss changes in landuse as you move longitudinally along the length of the river. To accomplish this, we would have had to delineate the spatial components of the basin upstream of each sampling point. This would have added a considerable amount of GIS work and was simply not feasible as part of this project.

The plot for the Muskingum River reveals a noticeable abiotic gradient (Figure 80). A slight biological gradient appears on the Wisconsin and Wabash rivers as well, albeit to a lesser degree. Results for the St. Croix, Scioto, Illinois and Minnesota rivers do not indicate the presence of a discernable longitudinal trend (Figure 80).

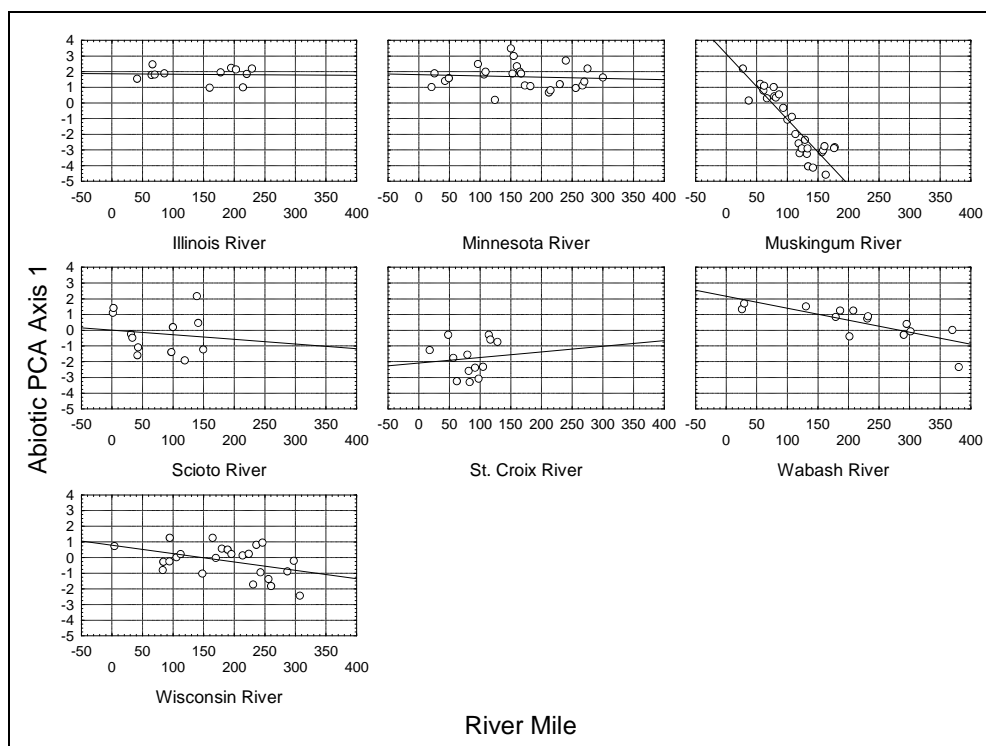


Figure 80. Abiotic PCA Axis 1 vs. River Mile.

5.3.2. Biotic Trends

FAQI scores were plotted against river mile to mile to demonstrate the presence/ absence of a functional biological gradient within individual rivers. Each plot is scaled to a uniform distance. As in the previous section, existing trends on rivers of lesser lengths are respectively compressed and therefore appear amplified.

The plots for the Muskingum and Scioto rivers reveal a noticeable biological gradient (Figure 78). A slight biological gradient appears on the Illinois and Wabash rivers as well, albeit to a lesser degree. Results for the St. Croix, Wisconsin and Minnesota rivers do not indicate the presence of a longitudinal trend (Figure 81). Results of FAQI plots were largely similar to those of abiotic plots (Figure 80).

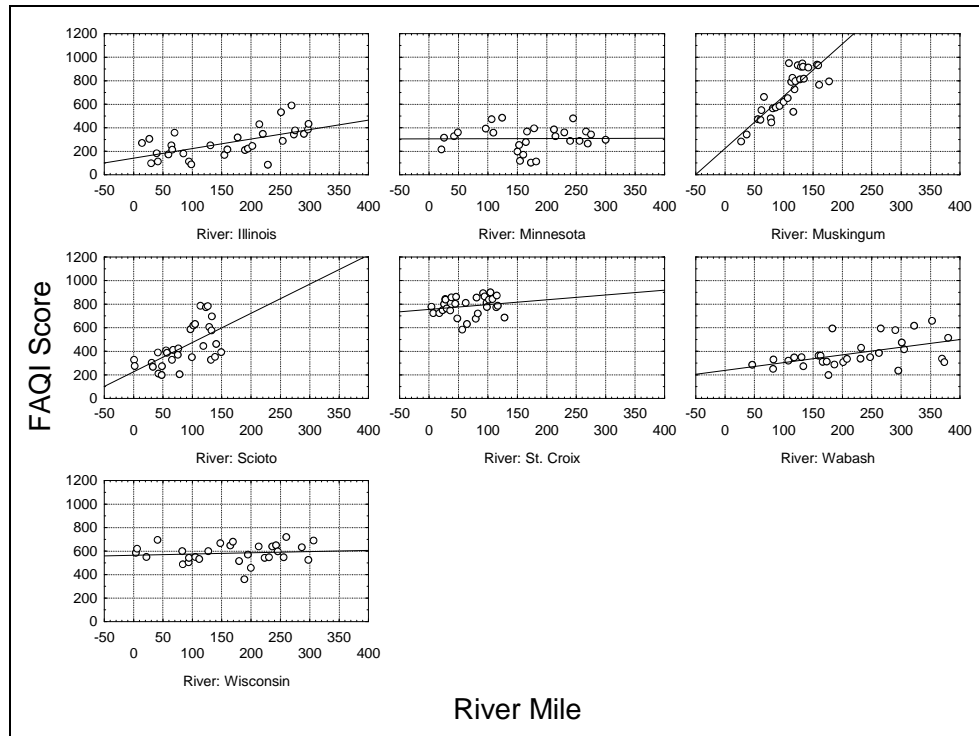


Figure 81. FAQI Score vs. River Mile; all rivers.

5.3.3. Abiotic – Biotic Interactions

The Muskingum River exhibited the strongest relationship between instream measures of abiotic condition and fish assemblage response (Figure 82). This is largely due to the differences between the ‘upper’ reaches of the river, which due to the site draw, actually fell within the Tuscarawas River. The Tuscarawas River is unimpounded and therefore more free flowing as compared to the lower reaches of the Muskingum. The differences between the two reaches is reflected in both the abiotic and biotic measures summarized in the above sections.

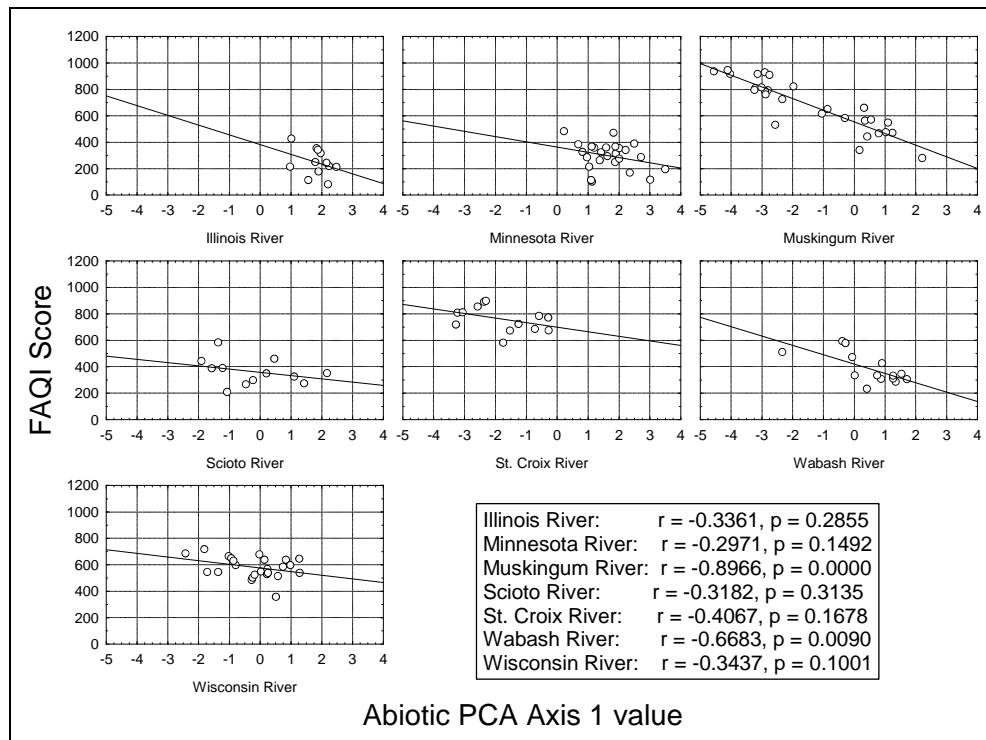


Figure 82. FAQI Score vs. Abiotic PCA Axis 1; all rivers.

5.4. INTER-RIVER COMPARISON RESULTS

5.4.1. Land Use

Land use in the seven target watersheds varied substantially. Cover types reflective of lesser human-induced impacts (forests, wetlands) were represented in higher densities within the St. Croix, Wisconsin and Muskingum River watersheds (Table 4-5). Human-induced cover types (agriculture) were present in higher densities within the Minnesota, Illinois, and Scioto river watersheds (Table 4-5).

Table 4. Watershed land use and cover types (area Km²) for the seven rivers surveyed.

| Land Type (% Total Watershed) | Muskingum | Scioto | Wabash | Illinois | Wisconsin | St. Croix | Minnesota |
|--|-----------|--------|--------|----------|-----------|-----------|-----------|
| Bare Rock / Sand / Clay | 0.00 | 0.00 | 0.00 | 0.03 | 0.02 | 0.00 | 0.00 |
| Commercial / Industry / Transportation | 0.77 | 1.35 | 2.12 | 1.25 | 0.56 | 0.32 | 0.67 |
| Deciduous Forest | 40.23 | 25.94 | 45.27 | 10.03 | 36.39 | 37.64 | 3.95 |
| Emergent Wetlands | 0.33 | 0.11 | 0.53 | 0.40 | 2.28 | 5.289* | 4.32 |
| Evergreen Forest | 1.92 | 0.59 | 1.57 | 0.44 | 3.88 | 3.51 | 0.08 |
| Grasslands / Herbaceous | 0.00 | 0.00 | 1.09 | 0.80 | 0.37 | 0.36 | 0.20 |
| High Intensity Residential | 0.30 | 0.55 | 0.80 | 2.15 | 0.17 | 0.06 | 0.21 |
| Low Intensity Residential | 2.62 | 2.44 | 4.55 | 1.87 | 0.37 | 0.29 | 0.77 |
| Mixed Forest | 0.73 | 0.17 | 0.55 | 0.07 | 5.47 | 4.74 | 0.16 |
| Open Water | 1.46 | 0.76 | 2.82 | 1.46 | 3.31 | 3.73 | 2.54 |
| Orchards / Vineyards | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| Pasture / Hay | 32.25 | 18.22 | 10.89 | 12.99 | 22.23 | 16.39 | 14.83 |
| Quarries / Stripmines | 0.20 | 0.10 | 0.06 | 0.09 | 0.04 | 0.03 | 0.05 |
| Rowcrops | 18.21 | 48.69 | 29.11 | 65.46 | 17.11 | 15.99 | 70.27 |
| Shrubland | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.07 | 0.05 |
| Small Grains | 0.00 | 0.00 | 0.00 | 0.22 | 0.00 | 0.14 | 0.82 |
| Transitional | 0.10 | 0.04 | 0.03 | 0.00 | 0.31 | 0.85 | 0.01 |
| Urban / Recreational Grasses | 0.31 | 0.84 | 0.50 | 1.21 | 0.21 | 0.23 | 0.36 |
| Woody Wetlands | 0.58 | 0.22 | 0.13 | 1.51 | 7.29 | 10.37 | 0.72 |

Table 5. Watershed land use proportion summary (scaled to watershed size)

| | Muskingum | Scioto | Wabash | Illinois | Wisconsin | St. Croix | Minnesota |
|---|-----------|----------|----------|----------|-----------|-----------|-----------|
| Total Watershed Area (km ²) | 20817.10 | 16879.80 | 28232.70 | 74603.20 | 30888.50 | 20030.20 | 43714.70 |
| % Agriculture Along Stream | 43.97 | 62.24 | 67.00 | 64.63 | 32.10 | 24.40 | 72.35 |
| % Agriculture on Steep Slopes | 4.92 | 4.99 | 6.53 | 6.97 | 4.10 | 3.30 | 7.70 |
| % Cropland on Steep Slopes | 1.76 | 3.38 | 4.59 | 5.71 | 1.70 | 1.60 | 6.24 |
| % Human Induced Land Use | 54.75 | 72.21 | 81.10 | 85.25 | 41.00 | 34.30 | 87.15 |
| % Forested Watershed | 42.89 | 26.70 | 15.68 | 10.54 | 45.70 | 45.90 | 4.19 |
| % Forest (Riparian) Along Stream | 42.23 | 28.56 | 19.31 | 16.29 | 43.00 | 49.60 | 9.98 |
| Total Roads (km) in Watershed | 2993.00 | 2270.00 | 10357.00 | 12245.00 | 3712.00 | 2028.00 | 5010.50 |
| No. Stream / Road Intersections | 336.00 | 339.00 | 779.00 | 745.00 | 416.00 | 147.00 | 365.00 |

We applied principal component analysis (PCA) to 27 landuse variables (Table 6). Those variables more closely associated with human impacts (agricultural land cover types) loaded negatively on PCA-1. Those more closely associated with less impacted conditions (forest and wetland cover types) loaded positively on PCA-1. Axis 1 explained 51% of the variance among all 7 rivers. Axis 2 explained an additional 19%.

Table 6. Factor loadings associated with PCA-1.

| <i>Factor-variable correlations (Factor loadings)</i> | |
|---|------------------------|
| Land Use Variable | Factor Loadings |
| % Human Induced Land Use | -0.98 |
| % Agriculture Along Stream | -0.95 |
| % Agriculture on Steep Slopes | -0.91 |

| | |
|--|-------|
| % Cropland on Steep Slopes | -0.90 |
| Rowcrops | -0.82 |
| Total Roads (km) in Watershed | -0.76 |
| Urban / Recreational Grasses | -0.76 |
| No. Stream / Road Intersections | -0.76 |
| High Intensity Residential | -0.74 |
| Commercial / Industry / Transportation | -0.69 |
| Orchards / Vineyards | -0.57 |
| Low Intensity Residential | -0.53 |
| Grasslands / Herbaceous | -0.41 |
| Small Grains | -0.33 |
| Bare Rock / Sand / Clay | -0.25 |
| Quarries / Stripmines | -0.14 |
| Shrubland | 0.33 |
| Pasture / Hay | 0.50 |
| Emergent Wetlands | 0.51 |
| Open Water | 0.58 |
| Deciduous Forest | 0.58 |
| Woody Wetlands | 0.82 |
| Transitional | 0.84 |
| Mixed Forest | 0.86 |
| Evergreen Forest | 0.89 |
| % Forested Watershed | 0.92 |
| % Forest (Riparian) Along Stream | 0.93 |

The Illinois River loaded the farthest on the negative end of PCA-1 with a value of -1.29 (Table 7), indicating that of the 7 rivers surveyed, it was most heavily influenced by human-induced disturbance. At the other end of the axis, the St. Croix River loaded the farthest, indicating minimally influenced conditions.

5.4.2. Abiotic Conditions

We combined 11 water quality and habitat variables into a single PCA (See Section 5.1.1) providing an integrated measure of abiotic condition. Averages of [abiotic] PCA-1 scores for individual sites were generated for each river (Table 7). Higher, positive values are reflective of generally poorer conditions (lower overall habitat quality, decreased clarity, embedded substrates) as previously shown in Table 2. Rivers previously identified in Section 5.4.1 as being dominated by anthropogenic landscapes loaded towards the positive end of the abiotic condition axis, indicating poorer instream habitat. As such, the St. Croix River was found to provide the highest quality habitat and the Illinois River the poorest quality, based on average PCA-1 values.

Table 7. Average abiotic (QHEI, Abiotic PCA, Land Use PCA) and biotic (T/E, Exotic, MIwb, & FAQI) values for the seven rivers.

| River | Average QHEI | Average Abiotic PCA Axis 1 Value ¹ | Land Use PCA Axis 1 Value ² | % of Sites with T/E Species | % of Sites with Exotic Species | Average MIwb (Min, Max) | Average FAQI (Min, Max) |
|-----------|--------------|---|--|-----------------------------|--------------------------------|-------------------------|-------------------------|
| St. Croix | 72.5 | -1.79 | 1.47 | 47 | 50 | 7.9 (6.0,9.6) | 782.5 (582.6,899.5) |
| Muskingum | 67.17 | -1.44 | 0.43 | 26 | 93 | 8.1 (6.3,9.4) | 699.2 (281.8,949.6) |
| Wisconsin | 58.84 | -0.19 | 1.00 | 21 | 83 | 6.9 (3.3,9.9) | 582.0 (359.8,719.7) |
| Scioto | 63.52 | -0.21 | -0.29 | 23 | 73 | 7.4 (4.2,10.5) | 438.4 (197.1,784.7) |
| Wabash | 59.6 | 0.49 | -0.69 | 20 | 90 | 7.1 (2.9,8.8) | 381.5 (199.0,658.9) |
| Minnesota | 58.53 | 1.68 | -0.64 | 19 | 86 | 5.7 (3.4,7.8) | 307.6 (101.3,483.9) |
| Illinois | 49.93 | 1.83 | -1.29 | 0 | 100 | 6.8 (4.6,9.4) | 270.5 (84.6,589.0) |

¹ Average PCA is the average score for the river based on all sites.

² Land use PCA values are based on one observation per river.

5.4.3. Biological Conditions

The presence of species listed as either Threatened or Endangered, whether on a Federal list or a State list, is usually an indicator of improved water quality and habitat conditions and generally reflective of a higher degree of overall biological or ecological condition. The existence, persistence and dominance of exotic species are indicators of more disturbed conditions.

The St. Croix River had the largest percentage of sites producing at least one T/E species, produced the fewest sites with at least one exotic species and produced the second highest average MIwb score and the highest average FAQI score (Table 7). At the other end of the spectrum, T/E species were not found at any of the sites surveyed on the Illinois River. However exotic species were captured from every site sampled. The Illinois River also produced the second lowest average MIwb score and the lowest average FAQI score.

A cumulative distribution function (CDF) was created for each river to indicate the probability of any particular observation of FAQI score falling at or below a specified value. The results demonstrate a range of biological condition on each river (Figure 83). The steeper an individual plot, the less variation that exists in that river with respect to FAQI score. Additionally, Figure 83 reveals maximum and minimum observed FAQI scores for each river relative to the others. By comparing CDFs, we can evaluate the degree of similarity between rivers.

The Minnesota and Illinois rivers had similar minimum FAQI scores (~90) and maximum scores ranged from 484 to 589. Sites on these rivers fell in the lowest observed scoring range. The St. Croix River had the narrowest range (583 to 899), while the Muskingum River exhibited the greatest (282 to 950) (Figure 83). Sites on these rivers fell in the highest observed scoring range. The CDF plots in Figure 83 effectively rank the seven rivers relative to their observed range of biological condition as described by the FAQI.

One can note from Figure 83 that the Muskingum River produced scores higher than the St. Croix River, but approximately 38% of the Muskingum scored lower than the minimum score observed overall on the St. Croix. Additionally, approximately 50% of the Muskingum and St. Croix Rivers produce values higher than the maximums observed on the other five rivers.

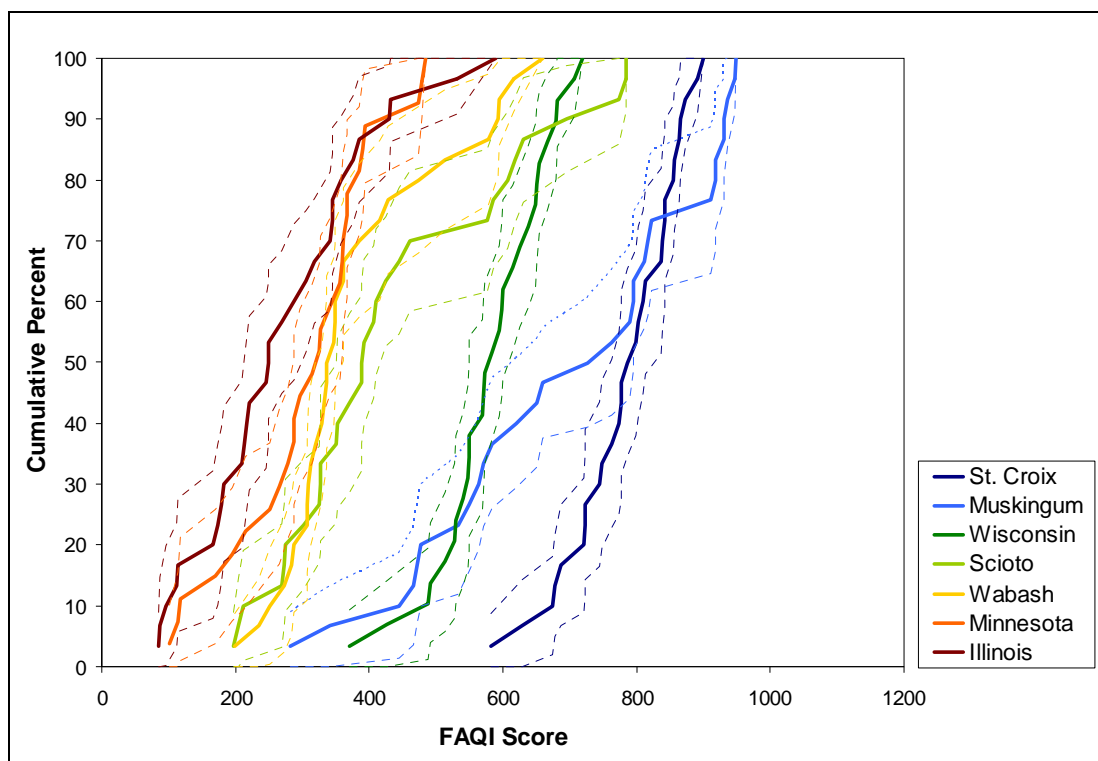


Figure 83. Cumulative distribution frequency (CDF) plots of site FAQI scores for each river.
(solid lines = CDF, hashed lines = 95% confidence bounds)

5.4.4. Landscape Influences on Abiotic Condition

As land use types/ practices change, our results suggest like changes in measures of abiotic condition within rivers. To document the influence of landscape scale features on changes in instream measures of physical and chemical habitat, we plotted averages for abiotic PCA-1 described in section 5.4.2 against landuse PCA-1 described in section 5.4.1 (Figure 84). The resulting plot (Figure 84) demonstrates a strong relationship between catchment attributes and measures of instream physiochemical habitat. Increasing conductivity and proportion of fine substrate correspond to increasing % human-induced land use, % agriculture and roads (Figure 84). Increasing average QHEI score, Secchi depth, % cobble, % gravel and average pH correspond to increasing percentages of natural land cover.

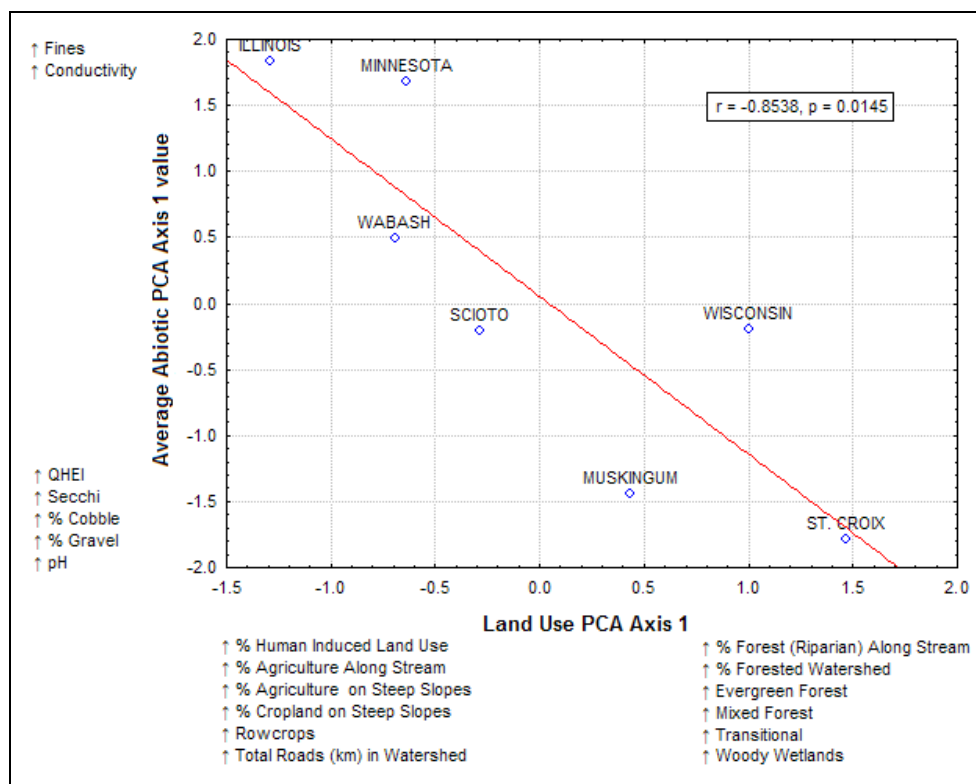


Figure 84. Average PCA Axis 1 value vs. Land Use PCA Axis 1.

5.4.5. Abiotic Influences on Biological Condition

In Section 5.1.3, as part of the FAQI validation process, we demonstrated the relationship between FAQI score and abiotic conditions captured by abiotic PCA-1. Here, we compress those results and plot average FAQI score for each river against average instream abiotic PCA Axis 1 (Figure 85). This plot also shows a strong relationship between abiotic habitat/ land use and biological condition. Those rivers with improved habitats, higher QHEI scores, lower turbidity, coarser substrates and higher pH, yielded higher average FAQI scores.

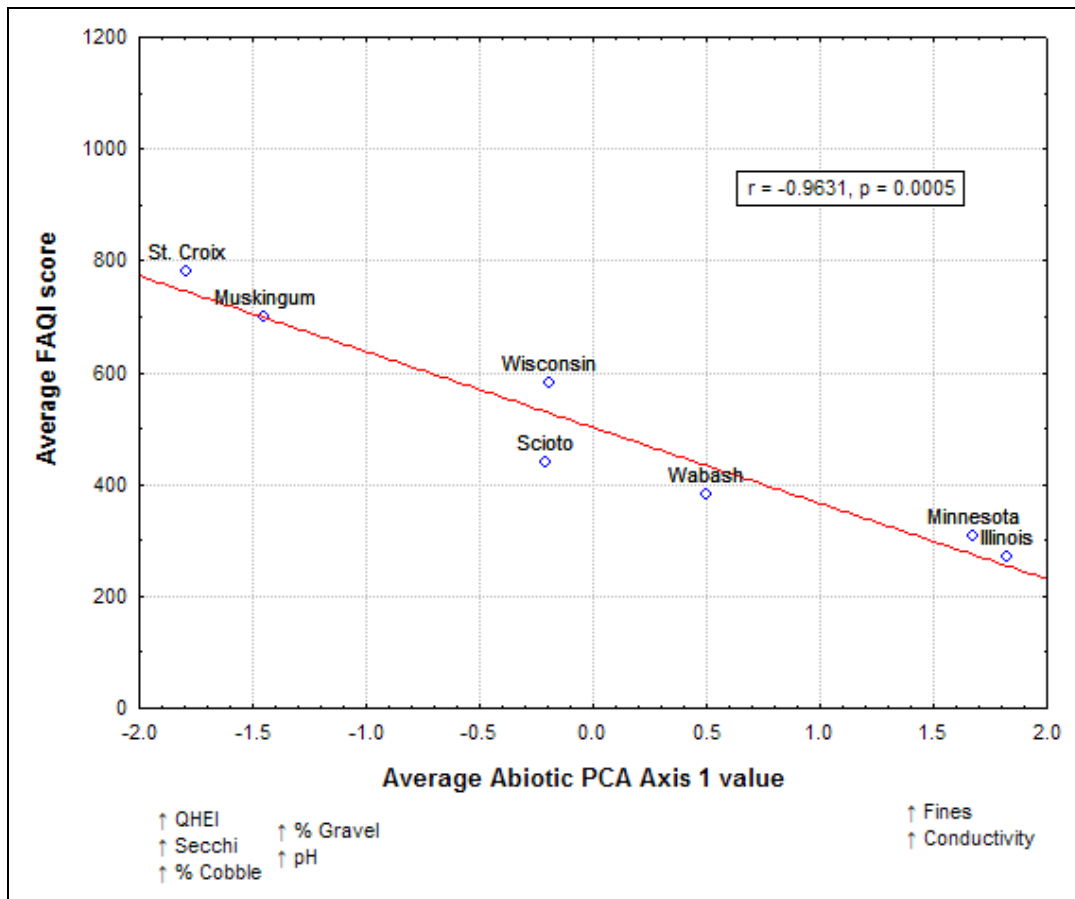


Figure 85. Average Abiotic PCA Axis 1 value vs. Average FAQI Score.

5.4.6. Landuse Influences on Biological Condition

Ultimately, we were able to link catchment disturbance to changes in biological condition across watersheds. We found a general pattern of FAQI, MIwb, presence of T/E species and absence of exotic species increasing as human disturbance in the watershed decreased (Table 7). Figure 86 shows the relationship between landuse and our fish index. The relationship is significant, and much stronger than we anticipated.

We did not however provide an evaluation of the variance explained by catchment factors as compared to the variance explained by local instream and riparian condition as that type of comparison would not be supported by the data collected. To accomplish this, we would have had to have tracked catchment scale changes on a site by site basis. We did not have that type of data available. That comparison would have been well beyond the original scope and intent of this particular project, but does warrant consideration for future efforts either arising from data generated by this project or by others.

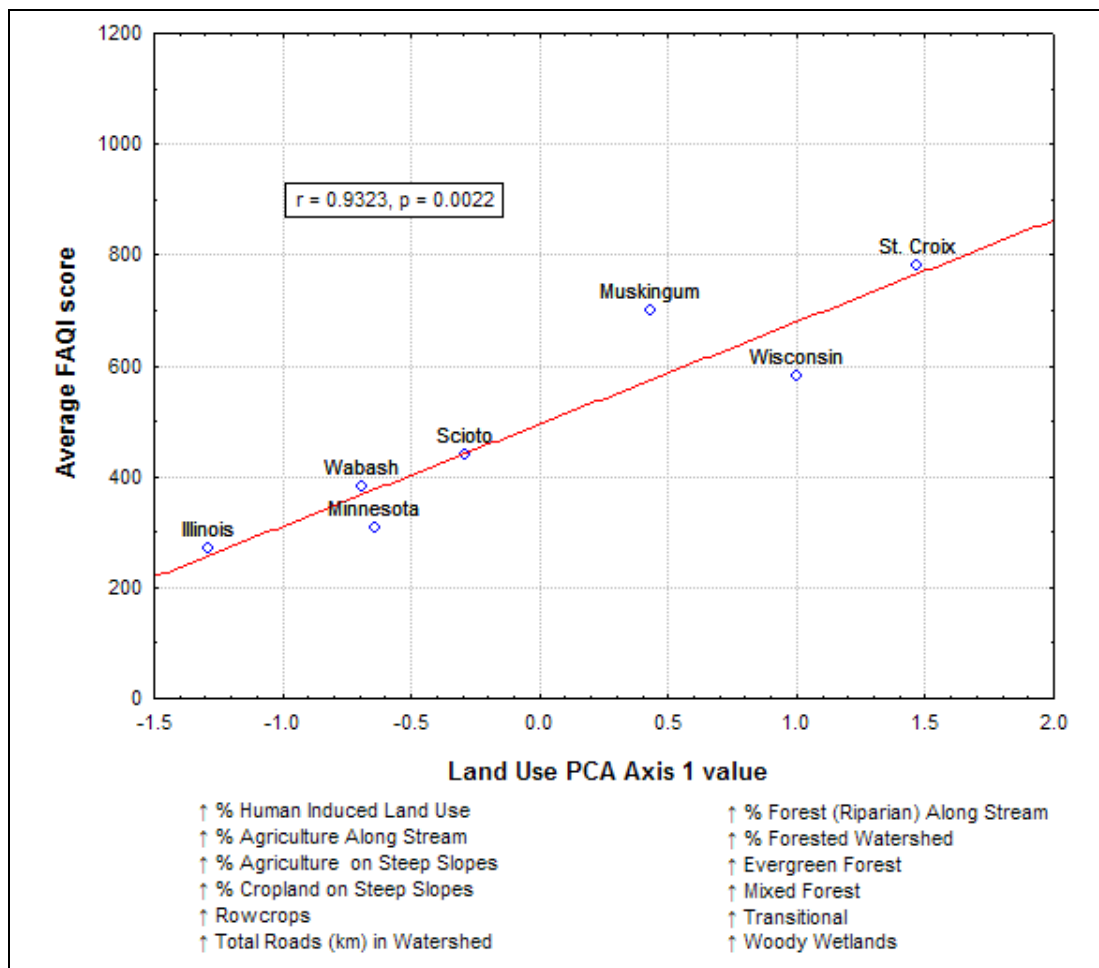


Figure 86. Land Use PCA Axis 1 value vs. Average FAQI Score.

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